ELECTRIC POWER STATIONS

By

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To

G. H. C.

and

E. W. C.

FOREWORD

by the late SIR LEONARD PEARCE,
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In the present days of stress, the minds and energies of Engineers are turned to many urgent tasks and the relative importance of many factors in the various problems which confront them have had to be readjusted temporarily to suit War conditions. However, when these unnatural conditions have passed and the days of peace return, there will be much reconstruction work to be done and Engineers will be called upon to play just as important a part as at present.

It is therefore essential that even in these strenuous days the technical studies of constructive engineering problems should not be lost sight of and that every effort should be made to keep abreast of modern thought.

The present book by Mr. T. H. Carr on "Electric Power Stations" is therefore particularly welcome at this time and it constitutes a most interesting review of the latest practice in design, more particularly in connection with the mechanical engineering side, of power station plant.

I feel sure that the book will be found to be of interest by the experienced engineer and the student alike and one particularly valuable aspect of the book is the extensive bibliography which is given at the end of each chapter, which will enable the reader to continue his researches in still further detail if he requires more data on any particular subject than that which has already been given in the book.

The advances which have been made in power station design since the beginning of this century are almost staggering and it is necessary sometimes to have a reference book in order to keep up to date with latest developments in the many fields. So great have been the advances in the many branches of engineering involved in the construction of electric power stations, that there has been a

great tendency for individual Engineers to specialise in a particular branch, but one important attribute of a good engineer is to have breadth of view, and the present book will, I am sure, be of great assistance in enabling specialists to maintain contact with branches of engineering other than their own.

S. L. PEARCE.

AUTHOR'S PREFACE

In these days of rapid electrical development the power station is probably the most important part of an electricity supply undertaking. The interconnection of a number of stations tends to reduce its relative importance, but nevertheless sight must not be lost of the inconveniences resulting from failure. The development can be divided broadly into three sections—industrial, commercial and domestic, the latter having progressed beyond all expectations in some countries.

The widespread use of electricity for the benefits of the community has been made possible by the continued efforts of engineers to take full advantage of its possibilities.

Its advantages are well known, and it is the duty of engineers to give an abundant and reliable supply of electricity at a price consistent with the economic standards prevailing. The transmission of large amounts of electrical power over wide areas is economical and practicable, and this in turn has had a decided effect on the choice of power station sites. The continual advances in generation, transmission and distribution plant also play important parts in power station design.

Power station design, unlike many other branches, calls for a wide knowledge of almost every branch of engineering, and in particular the Electrical, Mechanical and Civil sections. Every art and science is built up on first principles and it is only by their successful application that continued progress will be made. The duty of the designer is to choose from the plant available that which best fulfils the conditions to be met and to arrange it in the most economical way; always keeping in mind the necessity for subdivision of plant and abnormal conditions of operation, together with the possible dislocation due to failure of certain items or sections of plant. There are many ways in which the various items may be arranged in relation to one another, and the designer should reduce the subject to an economical association of essential principles.

The question of plant reliability must also be kept in mind, but it can be safely stated that the progress made during the past quarter of a century has resulted in remarkable improvements.

Power station plant has since its inception benefited by the

progress made in marine practice, and it is fitting to add the words of Mr. (now Sir) Winston Churchill, then First Lord of the Admiralty, when introducing the Navy estimates in the House of Commons on Tuesday, February 27th, 1940:

"In the last war I had a stream of lame ducks coming to dock for 'condenseritis,' or heated bearings, but now they seem to steam on almost for ever."

This book deals with the general principles governing design, construction and operation. A brief survey of the materials used and the construction of many items of plant and equipment are given primarily for reference purposes.

There are numerous excellent books and papers giving detailed descriptions of the majority of the plant used for power station service and no useful purpose would be served by including such descriptions. To simplify descriptive matter a large number of diagrams and sketches are included. Few books, however, deal with power station design, construction and operation. The author undertook the preparation of the present volumes at the request of the publishers, who felt that there was a need for such a publication. It is hoped that the book will prove useful to power station engineers, consulting engineers, designers, operatives, students and others.

The author wishes to express his sincere thanks to Sir Leonard Pearce for writing the Foreword to this book.

Grateful acknowledgments are also made to the editors of *The Electrical Review*, *Electrical Industries*, *Engineering and Boiler House Review*, *Power and Works Engineer*, *The Draughtsman*, *Electrical Engineer*, *Electrical Times*, *Mining Electrical Engineer*, *and Engineer Surveyors' Journal* for permission to use the author's articles which have appeared in their journals from time to time.

Free reference has been made to standard specifications and also published transactions of scientific institutions.

The final tracings of nearly all the drawings and diagrams have been the work of Mr. C. Brooke.

Finally the author wishes to express his appreciation of the assistance afforded him by the supply of information and illustrations from many individuals, electricity undertakings and manufacturers.

T. H. CARR.

CONTENTS

PLATES

(*All other illustrations in the text.*)

VOLUME ONE

CHAPTER I

SOME FUNDAMENTALS OF STATION DESIGN

Introductory. This volume deals broadly with the design, layout, construction and operation of steam electric power stations, of the present time, chiefly by way of description. The object in the design and operation of a power station is to generate electric energy safely, efficiently and economically.

The plant installed falls into two classes, the first is necessary to convert the heat energy of the coal or oil into steam and the second to convert the energy in the steam into electricity. The first process is carried out by the boiler plant and the second by the turbine plant.

If coal conservation was the most important factor then the highest thermal efficiency attainable irrespective of capital charges, would be the only answer. Present-day practice implies that the efficiency attainable be balanced against capital and operating costs of the plant required to attain this efficiency. The efficiency desired is therefore limited by economic considerations and is not allowed to become a matter of engineering technique alone.

Apart from economic considerations it will be appreciated that the better way of comparing stations or plant is on the basis of heat consumption and not fuel consumption.

Thermal efficiency is almost independent of the price of coal, whereas the economic thermal efficiency or commercial efficiency is almost entirely dependent on the price of coal together with load factor. Coal consumption has been progressively reduced (Table 1)

TABLE 1. *Thermal Efficiency and Coal Consumption*

Year	Highest Overall Thermal Efficiency, per cent. approximate	Lowest Average Consumption of Coal per Unit Generated
1908	8·50	3·47
1922	17·20	1·70
1926	21·51	1·36
1930	23·84	1·17
1938	27·70	0·90
1952	30·00	0·85

due to the following improvements: loading conditions, vacuum, design, size of unit, boiler efficiency, pressure and temperature, feedwater heating and reheating.

In many of the existing stations the scrapping of boiler and turbine plant has been justified by the advance in efficiency of plant, the high maintenance of old plant, the possibility of failure due to age, and the increased capacity of large modern units which may be accommodated on the same site.

The commercial success of any electricity undertaking depends upon the cheapness and reliability of supply and unless power be supplied at a price having advantages over private or other methods of generation, business will not be forthcoming.

The importance of reliability cannot be too highly emphasised and should take precedence over cheapness of supply. Some of the features which are desirable for power supply operation and development are compact area, many large power consumers and few geographical obstacles. Some of the obstacles are lack of adequate low temperature circulating water, limited facilities for transport of coal and frequent electric storms of extreme violence.

The chief thing is to provide a station and electrical system at a minimum capital cost consistent with a sound engineering job which results in the minimum operating costs throughout its useful life.

It is necessary to take into consideration the commitments of the undertaking, the nature of the service for which the energy is required and the probabilities of future development.

The whole aim in the building of a new power station should be to make progress in the economics of generation of electric power.

It is possible, but expensive, to approximate very closely to 100 per cent. security and the management of an undertaking should consider carefully what measure of security it may provide without overburdening the system with large outlays on duplicate plant.

This consideration calls for substantial engineering design and the use of efficient and reliable plant only. It is here that experience and collected data prove valuable guides. Inter-connection of stations tend to promote security of supply and at the same time reduce the cost of reliability.

In the building of a power station, involving several million pounds of capital, the time element becomes a factor of prime importance for the reason that until it is completed and in commercial operation the capital involved may to all intents and purposes be considered idle and consequently unremunerative. It

is therefore essential that a project of this magnitude should be completed as soon as possible in order to get a return on the capital invested. Some idea of the time required for carrying out large power station contracts will be gathered from the following examples :—

Station	Authority	Capacity Installed	Time
"A"	Power Co.	150 MW	25 months
"B"	,,	128 ,,	50 ,,
"C"	Corporation	190 ,,	50 ,,
"D"	,,	102 ,,	30 ,,
"E"	,,	60 ,,	45 ,,
"F"	,,	30 ,,	25 ,,
"G"	Power Co.	130 ,,	25 ,,

Because of shortages of materials and labour much longer periods are now inevitable.

Three principal requirements are outstanding :—

(1) The necessity of having an unobstructed field for planning ahead as far as possible and of being assured that such plans will not be departed from to any great extent.

(2) Adequate supply of capital, labour and materials allocated for power-station construction.

(3) Manufacturers of plant to have full facilities for production of the plant in such a way that the programme is carried out cohesively.

It seldom happens that one power station site is like any other in every respect, consequently different problems present themselves in the design of each new station. The differences in the problems have in part been responsible for the lack of uniformity of treatment of design and layout. Although the design and layout is straightforward it is essential that the designer should be fully acquainted with the plant to be installed and so obtain the most economical layout.

Power station design, construction and operation are so indissolubly bound together that each should go hand in hand in all problems. There are many ways in which the various items of plant may be arranged in relation to one another and it is necessary to know the behaviour of such plant under normal and abnormal conditions of operation. Experience only has given us this knowledge to which the developments in the design of power stations included are due.

Power stations are of national importance and a reputation for absolute continuity of supply is worth a great many tons of coal per annum. It has been suggested that by grouping by-product recovery plants, base-load semi-coke-fired power stations and low calorific value gas-fired gas turbines to deal with peak electrical loads great national economies in fuel could be effected. The engineer and architect should work hand in hand with an open mind for the hall-mark of good design is simplicity.

When planning a steam-electric power station it is necessary to take into account the following :—

(1) The raw material, coal, has to be taken to the boilers *via* bunkers similar conditions apply in respect of peat but vary somewhat for oil firing.
(2) The products of combustion in boilers—ash, flue dust and gases have to be disposed of.
(3) The steam generated in the boiler plant has to be delivered to the turbines by the shortest possible route.
(4) The cooling water has to be delivered to and discharged from the turbine condensing plant and may have to be re-cooled. Where re-cooling is necessary then spray-ponds and/or cooling towers will be required.
(5) The electrical energy produced by the alternators has to be delivered to the switchboards.

With a 200 MW station operating at 50 per cent. load factor some 400,000 tons of coal per annum will be required, and at full load the cooling water is of the order of 10 million gallons per hour. A cooling tower station would require make-up water at the rate of about 200,000 gallons per hour. The total weight of ash produced may amount to as much as 50,000 tons per annum.

PRINCIPLES OF STATION DESIGN

The economics of electric power production and distribution make it essential that generation should be carried on in large central stations, the location of these playing an important part in the cost of energy generated. The ideal position is at the centre of gravity of the " loads " on the distribution system, thus avoiding very long transmission lines. The shortening of transmission lines and/or cables reduces the capital cost and losses associated with them, even with a lower thermal efficiency due to the use of cooling towers compared with a riverside site some considerable distance from the load centre.

It should be pointed out that where a new station is an addition to an existing network its location may not be required to be near

the load centre and the relative costs of energy transmission and coal transport are in this respect not nearly so important.

In general there are three choices :—

(1) At the load centre.
(2) At or near the coal mine.
(3) On an estuary site to which the coal can be delivered by sea.

The choice of site may be dictated partly with the idea of obtaining adequate spare land in the vicinity of the station to which it may be possible to attract works requiring large power supply as a result of the advantageous terms which could be arranged.

It may be justifiable to have a number of stations, such a case being where there are scattered communities separated by large distances. The centre of gravity of the electrical system may be determined by plotting all the principal load centres with their maximum half-hourly demand in kVA and by taking moments first about a north to south axis and then about an east to west axis or alternatively from some other arbitrary datum lines. It is usually desirable to work in miles and kVA and assume 1,000 kVA to equal one power unit. A simple system is illustrated in Fig. 1. The working is as follows :—

$$\text{Position of CoG} = \frac{\text{Sums of moments}}{\text{Total loading}}.$$

$$\text{Moments about OY } \bar{y} = \frac{A_a + B_b + C_c + D_d, \text{ etc.}}{A + B + C + D, \text{ etc.}}$$

$$\text{,, \quad ,, \quad OX } \bar{x} = \frac{A_{a1} + B_{b1} + C_{c1} + D_{d1}, \text{ etc.}}{A + B + C + D, \text{ etc.}}$$

Substituting figures, we have

$$\bar{y} = \frac{(10 \times 2) + (2 \times 5) + (2 + 10) + (5 \times 3) + (5 \times 4)\ (10 \times 10) + (10 \times 3) + (5 \times 5) + (5 \times 9)}{10 + 2 + 2 + 5 + 5 + 10 + 10 + 5 + 5}$$

$$= \frac{285}{54} = 5{\cdot}25 \text{ miles from OY.}$$

$$\bar{x} = \frac{(10 \times 15) + (2 \times 15) + (2 \times 15) + (5 \times 12) + (5 \times 8) + (10 \times 10) + (10 \times 5) + (5 \times 2) + (5 \times 5)}{54}$$

$$= \frac{495}{54} = 9{\cdot}2 \text{ miles from OX.}$$

In practice it may not be possible to obtain such a site as the following factors have to be considered :—

(1) The cost of land should be reasonable. Where a station must of necessity be situated in or near a city the cost of land is in general much higher than in urban or rural areas, and in addition it may be necessary to carry out property condemnation to obtain the requisite site area. Furthermore, the fact that a specific piece of property is being considered by a supply authority for the purpose of erecting a power station may enhance its value appreciably and in such cases shrewd buying is desirable.

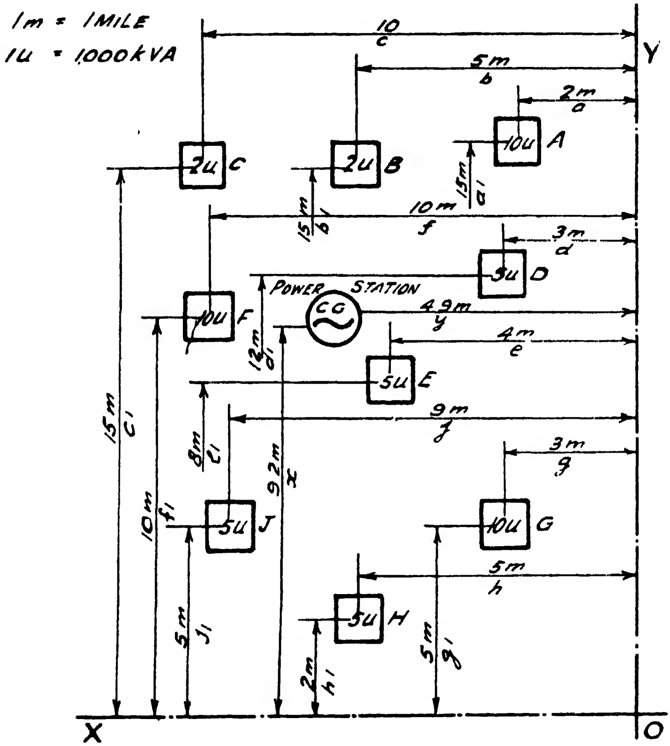


FIG. 1. Method of Determining Centre of Gravity of Electrical System.

(2) A plentiful supply of cooling water is desirable. The use of large and highly efficient concrete cooling towers and multistage feed-water heating has effected large reductions in the quantity of cooling water required. The water may be taken from a river, canal, sea or sewage outfall. Some 500 tons of cooling water are required for every ton of coal burned. Where cooling towers are employed a sufficient quantity of water to provide for make-up is necessary. Suitable water in ample quantity will also be required for boiler-feed purposes.

(3) Availability of cheap fuel and ample railway facilities for coaling and a suitable river or canal as an alternative for water-borne coal. A navigable waterway and sea route to the coal fields are assets to certain power stations.

In some cases it is possible to place a station near the coal mine and convey the coal almost direct from the shaft to the boiler bunkers.

Oil-burning stations may also have to be considered.

(4) The civil engineering work involved should be a minimum. This implies a level site and a good foundation at a reasonable depth. Minerals under and in the vicinity should not have been worked. The possibility of a site on a seaboard may be impracticable or uneconomic if the depth of the rock bed is excessive and the tidal effect makes the supply of cooling water a difficult proposition. If possible the site conditions should be such that piling or blasting is not required. A firm rock bottom not too hard is desirable.

Ample area to meet ultimate requirements and serve as a running and reserve coal storage. The site should not be surrounded by residential property and should be isolated to prevent danger from fire breaking out in and spreading from neighbouring buildings.

(5) Care should be taken to limit the possibility of nuisance to the neighbouring property and its occupiers, due to the emission of smoke, grit, noise, steam, water vapour, etc.

This condition may dictate the type of boiler plant it is possible to instal, *i.e.*, stokers in preference to pulverised fuel or alternatively oil-fired boilers. Stokers appear to produce less " fly ash," and the duty of the flue gas cleaning plant is not nearly so severe as with pulverised fuel boilers. Not only must the cleaning plant be efficient but it must be reliable and capable of operating for long uninterrupted periods.

Before a station is erected it may be necessary to guarantee that all known precautions will be taken to eliminate any such nuisance.

A clause such as the following may be included : " The supply authority shall in the construction and working of the power station take the best known precautions for the due consumption of smoke and for preventing as far as reasonably practicable the evolution of oxides of sulphur, and generally for preventing any nuisance arising from the power station or from any operations thereat."

The building of a power station may give rise to objections and in one case the following were stipulated :—

(*a*) It should not be built if there is an alternative site.

(*b*) The building should be of materials and design to harmonise with its surroundings.

(*c*) There must be adequate control of smoke, fumes and steam emission.

(*d*) There must be no unsightly coal storage dumps.

(6) Facilities for the disposal of ashes, *e.g.*, large areas of land near the site which are flooded and valueless for development, quarries, etc.

(7) At some later date it may pay to change the site of the station and supply the system from another station where power is produced at reduced cost.

(8) The rates and rents should be low and housing accommodation in the immediate neighbourhood should be adequate.

(9) The surrounding country should afford ample room for the establishment of industries requiring large amounts of electricity at the lowest possible price. The geographical position should meet existing and anticipated future demands whilst access for both overhead and underground feeders is desirable.

(10) The choice of site should allow for economical extensions consistent with the estimated growth of load.

(11) In view of the rapid development of aerial warfare it may be essential to limit the capacity of stations and choose sites which are away from densely populated and industrial areas. The inter-connection of stations is a safeguard in this respect providing physical and electrical separation is included.

(12) Avoidance of obstruction to flying in the vicinity of aerodromes.

(13) The effect on fishery and other interests of the use of river or estuary cooling water.

(14) The considerations of Town and Country Planning, Royal Fine Arts Commission, land utilisation generally in the case of urban stations.

(15) The location of the site in relation to the requirements of national defence.

From this preview it will be appreciated that the choice of site is fundamental to the efficient supply of electricity and generally speaking may be of greater importance than the quality of plant installed on it. Plant can be replaced when it becomes inadequate or obsolete whereas the main features of the site, whether good or bad, are permanent.

The essential principles of electric power station design are: reliability, minimum operating and maintenance costs and minimum capital cost.

These depend to large extent on the following :—

Simplicity of design.
Sub-division of plant and apparatus.
Labour-saving equipment.
Extensibility.
Organisation.

Fig. 2 shows the general flow sheet of a power plant.

Simplicity of Design. Simple and sound design and layout are desirable features in all sections of a station for good layout of plant simplifies building and civil engineering works apart from aiding operation.

There should be a minimum of auxiliaries, a limited number of floor levels and sufficient area to provide a spacious but economical layout of plant. These are important features of simplification and should always be borne in mind. A compact station if well planned is just as accessible and easy to operate as one in which the floor area though considerably greater is not used to best advantage. The volume and floor area per kW should be a minimum consistent with operating conditions. The design of the plant should be as simple as possible even at the expense of striving for thermal records. In carrying out the detailed design and in the construction of a power station the features of simplicity, compactness and com-

mercial efficiency should always be kept in mind. Thermal economy should go hand in hand with overall financial efficiency.

A standardised design for each unit may not always be economical due to rapid advances in science, but the value of simplicity and

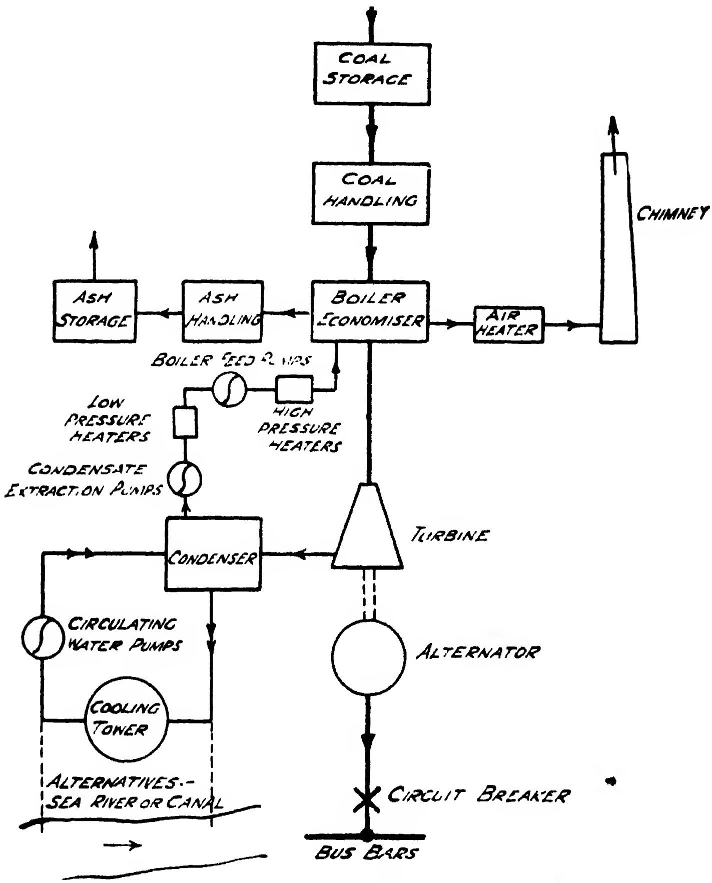


Fig. 2. Station Flow Sheet.

standardisation should be carefully considered before making radical changes. Generally speaking, a simple design of plant is relatively cheap in first cost, reliable and does what is expected of it. On the other hand, designs departing from general practice have had many difficulties and have usually taken a number of years to bring them up to expectations. Economical operation and performance together with convenience of access to all essential apparatus and auxiliaries and ease of control are important features.

In designing a station it is of great importance to standardise as far as possible since the capital cost is reduced, space is saved, repairs and maintenance charges reduced and administration is facilitated. This is an important feature in any station but more so when the station is abroad and where spare materials take a considerable time to be delivered to site. It would be unwise for a country far from manufacturing centres to adopt frills and technical novelties. Reliability is of primary importance, economy being sought in directions other than ultimate thermal efficiency. Simplicity of equipment and straightforwardness of layout should be studied with great care. Operation is rendered easy and supervision simplified if all auxiliary plant is readily accessible and levels of illumination are adequate. Cleanliness should be more of a consequence than a virtue, and efficient maintenance rather a state than an activity. Under these conditions economical operation is almost assured.

Sub-division of Plant and Apparatus. Sub-division of plant and apparatus is essential if complete shut-down is to be guarded against. Furthermore, it promotes safety in operation and facilitates maintenance.

Sections of plant may be completed and put into service separately, thus reducing time and cost of construction.

The trend appears to be towards one boiler per turbine and one alternator for each section of feeders with arrangements for interconnection under maintenance or emergency conditions.

Labour-saving Equipment. The inclusion of labour-saving equipment is desirable providing reliability is unimpaired and the cost is reasonable.

The automatic equipment installed should be reliable and such that the human element may be safely dispensed with, particularly where it performs important functions. In some cases it may be justifiable to include both automatic and manual controls so that the latter is always available in case of emergency.

Automatic control gear is now incorporated whenever possible, and this gear is centralised so that few operatives are required. In one arrangement all the main operating controls of two turbo-alternators and of two boilers are arranged so that they are under the direct control of one man. This is accomplished by placing the turbo-alternators in pairs in mirror symmetry, steam end to steam end, by eliminating above the turbine operating floor the wall normally existing between the boiler house and the turbine house and by grouping the four control panels ; *i.e.*, two for boilers and

two for turbines in an open U form in the area between the turbines and boilers. By this layout it is possible to employ at each 100 MW control centre a highly trained man and to provide four comparatively unskilled attendants trained in the observation of the operation of a particular group of auxiliaries. To this end the following auxiliaries are arranged in the groups given :—

Boiler House Ground Floor. Forced-draught fans, coal mills, separators and feeders and mill exhauster fans. Also on this floor and under the care of an additional plant attendant is the ash-handling plant.

Boiler House Firing Floor. Induced-draught fans, dust collectors, air heaters, coal weighers ; and also readily accessible from this floor, the fuel-oil pumps and the coal and oil burners:

Turbine House Ground Floor. Circulating water pumps and screens, condensate extraction pumps and circulating water chlorination plant. Also grouped on this floor and under the care of an additional plant attendant are the boiler feed pumps and evaporators.

The dust collectors, induced-draught fans and main flues can be installed externally to the boiler-house building and between it and the chimney, thereby reducing the size and cost of that building and avoiding higher temperatures within it.

Extensibility. Usually the future requirements of a power station are not definitely known, but the present types of plant have now come within such narrow limits of maximum possible efficiency that no great changes are likely to take place in the near future.

Speaking generally, a power station may be extended without appreciably affecting the ultimate cost and should therefore be commenced on the smallest scale possible.

In the development of almost every electricity undertaking there is the need for constant revision of certain items and within recent years many of the earlier stations have been modernised. It is interesting to note some of the factors which have had to be considered :—

(1) Maximum thermal efficiency without radical departure from the plant characteristics of the original station and with a minimum addition to existing buildings, coal and ash handling plant.
(2) Minimum cost of additional civil engineering works.
(3) Facilities for the improvement of operation, a notable example being the provision of a separate control room in place of the original switch control board in the turbine house.
(4) The installation of plant which has—bearing in mind the total annual cost including capital charges—taken advantage of the improvements made in such plant and will assist to prove and further enhance its application.

Although existing buildings may be adequate for housing new and larger units of plant, it usually proves a more difficult task than commencing on a new site. Instead of the buildings being designed to accommodate the plant, the plant itself has to be designed within the limits of the existing buildings and a considerable amount of scheming and arranging is usually inevitable to obtain this end. Stations which started with steam pressures of from 200 to 400 p.s.i. have found it economically justifiable to superimpose a very high-pressure system—600 to 1,200 lb.—on the existing system and so improve the heat rate of the station. The saving in heat rate must be sufficient to balance the additional fixed charges on the higher pressure plant.

Organisation. This is the structure through which the functions of management are applied, and the form it takes determines the responsibilities and relationships which each individual bears to another. With the rapid increase in capacities of stations together with the complexities and technicalities of the plant installed, organisation has become of vital importance.

In the power station it is the duty of engineers to deal with problems of design and construction of plant and buildings, the installation, maintenance and operation of all power plant and equipment, the records of operation and the internal organisation and operation of the plant for making the station an efficient unit from both a technical and commercial standpoint. Plant availability is a factor of prime importance and as much depends on the maintenance department it is essential that a sound and adequate staff be chosen. As in other industries, the human factor is all important and special attention is necessary in the selection of staffs if good team work is to result. It is only by sympathetic appreciation of individual troubles that apparent difficulties will be overcome and whilst one can never hope for an ideal organisation some degree of satisfaction is obtained if the majority of the persons making up a complex unit are happy. There is much to be said for the personal touch between the management and the station staffs. This condition tends to disappear on the larger concerns where the electricity supply operational details are based on elaborate statistics compiled in great detail and probably at great expense. The whole system upon which an undertaking is operated so far as the relations between the employers and employed are concerned should receive very careful consideration. When additional employees are required a selection may be made from elected representatives of the existing employees providing the management approve of them.

The whole of the staff and workmen may participate in a bonus scheme which so far as the power station personnel are concerned is based upon the efficiency obtaining.

Various forms of organisation are in use and are discussed more fully in Volume II.

The principles outlined cannot always be met and in practice absolute perfection is rarely justified economically.

RATING OF PLANT

Regarding station performance, a study will first be made of the power requirements for existing and future load conditions and in this way the capacity may be fixed.

The cost of the fuel delivered and the probable cost of energy transmission are also required, whilst in the case of an existing station the station heat balance will require investigation before proceeding with extensions.

In estimating the economy of production for a new station it is necessary to keep an accurate record of all costs, for the total cost depends to a great extent on the degree of refinement desired in the reduction of heat rate.

In deciding upon the rated output of the various units due consideration should be given to :—

(1) Peak load.
(2) Periodical overhaul.
(3) Breakdown.

Should the normal load be equal to the economical rating of one unit only, it may be possible to take care of the peak load with the overload capacity of that unit, but to provide for periodical overhaul, and as stand-by against failure, additional units would be essential Whether any or all of these features are best served by additional units or by overload capacity depends upon the number of units installed and on the relation between the peak and overload capacity procurable. In this country the grid system brought about a new outlook regarding new generating plant. The co-ordination of generating plant development has perhaps proved to be one of the greatest contributions of the grid towards the advancement of the supply industry. Previously, new plant facilities were provided piecemeal as required by the load increment of the individual undertaking and the size and type of turbo-alternator and boiler units were more or less rigidly determined by local load prospects in the years immediately ahead.

It is essential that the plant should operate economically at normal rating for little regard need be paid to the increased cost of overload running as the increase would be more than balanced by the saving in capital cost.

During recent years the progress in the size of unit installed has undergone considerable change, due mainly to many improvements in manufacture, bringing about increased reliability in operation. A boiler develops its maximum efficiency under steady load conditions at a definite rate of evaporation and if this is raised or lowered the sum total of the incidental thermal losses increases.

Generally speaking, boiler efficiency increases with calorific value, but cases are on record where pulverised fuel boilers have given a higher station thermal efficiency with a C.V. of 9,500 compared with a C.V. of 10,500 B.Th.U. per lb. for almost identical conditions.

The maintenance of maximum efficiency at any particular load necessitates close supervision unless automatic control is provided.

The items making up a complete unit are: boilers, turbine, alternator and circuit-breaker. The ideal condition would be for each item to have the same degree of reliability and availability. This would bring about a considerable reduction in the plant to be installed, that is, spare plant would be reduced to a minimum. In this country standardisation of plant is proceeding steadily and turbo-alternators each of 60 MW capacity operating at 900 p.s.i. and 900° F. and 30 MW sets operating at 600 p.s.i. and 850° F. are now standard. Still higher pressures and temperatures are being provided for a number of 60 MW sets, operating at a pressure of 1,500 p.s.i. and temperature of 1,050° F. At one new station some six 100 MW sets will be installed to operate under similar high pressure and temperatures. The boiler superheater outlet steam conditions are 1,600 p.s.i. and 1,060° F. Reheat cycles are also contemplated with an initial steam pressure of 1,500 p.s.i. at a temperature of 975° F., with reheat to 950° F.

In America a 120 MW tandem-compound, 3,600 r.p.m. steam turbine unit with its steam generator, pumps, heaters and condensers operating at a pressure of 4,500 p.s.i. at the turbine throttle is contemplated. Initial temperature is 1,150° F., reheat is at 1,050° F. with a second reheat at 1,000° F. Thermal performance is expected to be 8,500 B.Th.U. per kWh.

The unit system, whereby a single boiler provides steam for a single turbo-alternator, is being widely adopted, the size of these

boilers ranging from 515,000 lb. per hr. to 550,000 lb. per hr. evaporative capacity to serve the 60 MW sets, and 800,000 lb. per hr. to 840,000 lb. per hr. to serve the 100 MW sets. Unit sets of 150 MW are already in operation in the U.S.A. at 2,000 p.s.i., 1,050° F. and with reheat to 1,000° F. Orders have been placed for a 200 MW set operating under almost identical conditions. It is technically possible to build 300 to 400 MW sets as cross-compound units, while metallurgical development might permit the use of higher temperatures.

It is usual to classify the output of units under two headings :—

(1) Economical rating.
(2) Maximum continuous rating.

the latter generally being 20–25 per cent. above the economical rating.

A recent tendency is to specify only a continuous rating for boiler plant.

In selecting the basis of rating a station, the probable load factor, together with the possibilities of interconnection, should be duly considered. Under independent operation it is considered sound engineering practice to have reserve generating plant equal to the largest turbo-alternator. Another factor to be borne in mind is that it is usually necessary to plan plant extensions some four years ahead of the required date of operation. The outage of boiler plant has been greatly reduced and the optimum condition of being able to steam a boiler from one annual survey to the next has practically been reached.

The station load factor is the ratio of the average load to the maximum load during a prescribed period of time, and is usually expressed as a percentage or is given by :—

$$\frac{\text{units generated per annum}}{8{,}760 \times \text{maximum demand}}$$

$$\text{or} = \frac{\text{units generated} - \text{works units}}{\text{Hours in week or month} \times \left(\begin{matrix}\text{M.D. on}\\ \text{generators}\end{matrix} - \begin{matrix}\text{M.D. on}\\ \text{works}\end{matrix}\right)}$$

This load factor definition requires some explanation otherwise confusion may arise in its application, *e.g.*, a 30 MW set running at one-tenth load continuously for one year would have a load factor of 100 per cent., whereas it would actually be 10 per cent.

$$\text{The plant load factor} = \frac{\text{units generated per annum}}{8{,}760 \times \text{station kW}}$$

$$\text{or plant load factor} = \frac{\text{units generated}}{\text{sum}\begin{pmatrix}\text{M.C.R. of each set} \times \\ \text{its running hours}\end{pmatrix}}$$

Another factor of importance is the Utility Factor, which may be defined as the ratio of units generated or sent out per annum to the capacity of the plant installed in the station, *e.g.* :—

100 MW capacity, 50 MW maximum load, 80 per cent. Load Factor.

$$\text{Utility Factor} = \frac{50 \times 0{\cdot}8 \times 100}{100}$$

= 40 per cent., which is relatively low although the load factor is high.

$$\text{The Availability Factor} = \left(1 - \frac{\text{Outage Hours}}{\text{Annual Hours}}\right) . 100$$

$$\text{Plant Operating Factor} = \frac{\text{Service Hours}}{\text{Period Hours}} . 100$$

$$\text{Generated Running Load Factor} = \frac{\text{units generated}}{\begin{matrix}\text{Station Running} \\ \text{Hours}\end{matrix} \times \begin{matrix}\text{MD on} \\ \text{generators}\end{matrix}}$$

$$\text{,, \quad ,, \quad (sent out)} = \frac{\text{units generated} - \text{Works units}}{\text{Station Running Hours} \times \begin{pmatrix}\text{MD on} \\ \text{generators}\end{pmatrix} - \begin{matrix}\text{MD on} \\ \text{works}\end{matrix}\Bigg)}$$

$$\text{Undertaking Load Factor} = \frac{\begin{matrix}\text{Units generated} - \text{Units} \\ \text{Exported} + \text{Units Imported}\end{matrix}}{\begin{matrix}\text{Total Hours} \times \text{MD on} \\ \text{Undertaking}\end{matrix}}$$

$$\text{Power Factor of Station} = \frac{\text{kW}}{\sqrt{\text{kW}^2 + \text{RkVA}^2}}$$

or (kWh and RkVAh)

Diversity Factor—is the ratio of the sum of the maximum loads of the individual feeders supplied during a given period to the maximum load on the station during the same period, or

$$= \frac{\text{sum of feeder maximum demands}}{\text{station maximum demand}}$$

In determining the number and size of the various units to be installed, a careful analysis of the anticipated load conditions, together with the estimated growth of load, are primary considera-

tions. It is usual to provide for an increase of approximately 6 to 10 per cent. per annum in station capacity, depending upon the developments in the area served.

Fig. 3 gives a typical weekly load curve for a large undertaking.

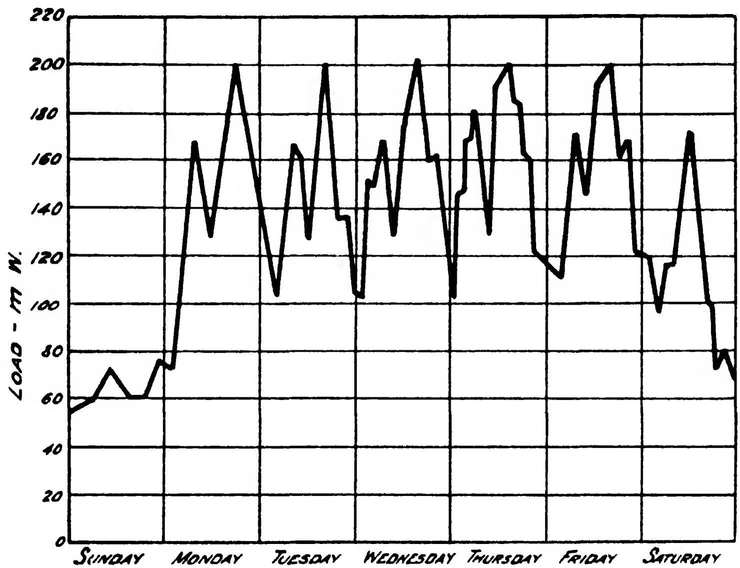


FIG. 3. Typical Weekly Load Curve.

During recent years the trend in power station design has been to instal units of large capacities as economies may be effected, space factors reduced and larger power loads handled.

Fig. 4 shows the relation of capital cost to size of plant units and may be taken as a guide to present-day practice.

The capacities of stations may be limited, and the sizes of the various units being chosen principally on the basis of overall economy of capital and operating costs. The type of boiler plant to be installed, *e.g.*, pulverised fuel or stoker fired or oil fired, will also have some effect on the size of boiler units chosen. The units should be chosen so that the outputs ensure that át all loads which occur throughout the operation periods (daily and weekly) it is possible to have any combination of units operating under the most economical conditions.

Taking the case of turbo-alternators, the steam consumption goes up rapidly on low loads (Fig. 5) and it is therefore very uneconomical to have large sets running for long periods under conditions

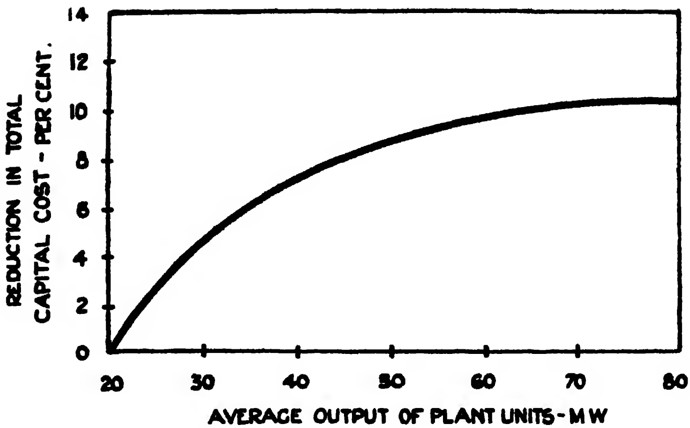


FIG. 4. Relation of Capital Cost to Size of Units.

of much less than about 50 per cent. M.C.R. The normal economical rating is usually 80 per cent. of the maximum continuous rating.

In purchasing sets the steam consumption figures will be carefully considered and to facilitate comparison between various offers, consumption figures at three or four definite loads are desirable. The average efficiency may then be calculated for the selected load range by dividing the sum of the products of loads and corresponding consumptions by the sum of the loads for which the consumption values have been given.

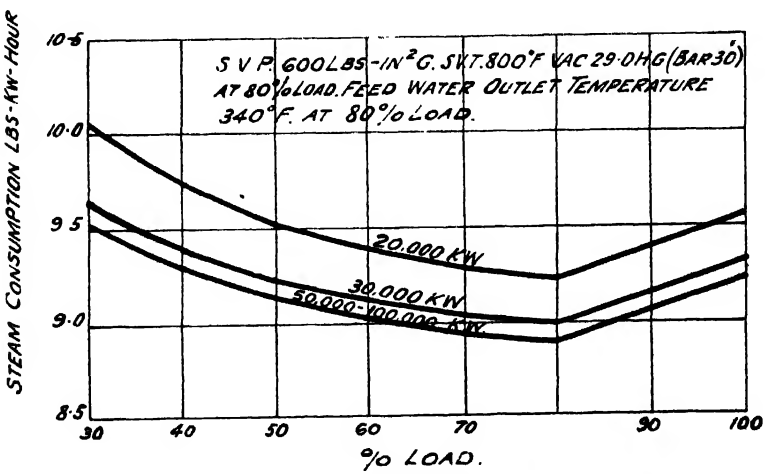


FIG. 5. Typical Steam Consumption Curves of Steam Turbo-alternators.

Take two examples as follows where steam conditions are 300 lb. and 750° F. and a river station :—

Load kW	Steam Consumption lb. per kWh		Products	
	"A"	"B"	"A"	"B"
30,000	9·77	9·80	$293{\cdot}10 \times 10^3$	294×10^3
24,000	9·44	9·50	$226{\cdot}56 \times 10^3$	228×10^3
18,000	9·56	9·65	$172{\cdot}08 \times 10^3$	$173{\cdot}7 \times 10^3$
			$691{\cdot}74 \times 10^3$	$695{\cdot}70 \times 10^3$

average steam consumption per turbo-alternator " A "

$$= \frac{691{\cdot}74}{30 + 24 + 18} = 9{\cdot}60 \text{ lb. per kWh}$$

average steam consumption per turbo-alternator " B "

$$= \frac{695{\cdot}70}{72} = 9{\cdot}66 \text{ lb. per kWh}$$

The importance of a small variation in steam consumption can be seen by comparing sets " A " and " B " in which case there is a difference of 0·06 per kWh at economical rating.

Assuming sets to be running for 7,500 hours a year at 24,000 kW, then total kW hours generated will be equal to 24,000 × 7,500, and if 7·66 lb. of water are evaporated per lb. of coal and coal costs £1 per ton, the additional cost due to set " B " may be estimated

24,000 × 7,500 kWh.

24,000 × 7,500 × 0·06 lb. of steam.

$$\frac{24{,}000 \times 7{,}500 \times 0{\cdot}06}{7{\cdot}66} \text{ lb. of coal}$$

$$\frac{24{,}000 \times 7{,}500 \times 0{\cdot}06 \times 1}{7{\cdot}66 \times 2{,}240} \text{ £ cost}$$

$$= \text{£}630 \text{ per annum.}$$

The steam consumption of turbines may be taken as increasing at the rate of approximately 0·25 to 1 per cent. per annum, but little information is available on this matter.

CHOICE OF CYCLE ARRANGEMENT

The cycle arrangements met with in practice may be broadly enumerated under the following heads :—

(1) Regenerative.
(2) Reheating.
(3) High-pressure topping.
(4) Binary vapour.

The regenerative cycle, Fig. 6, is essentially a turbine "stage

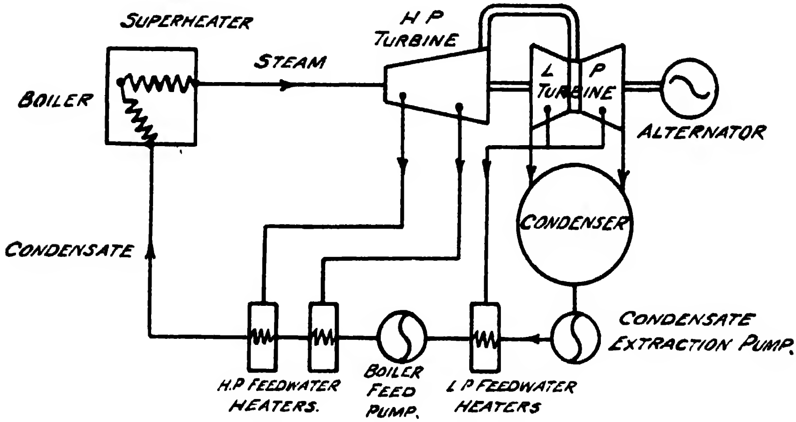


FIG. 6. Regenerative Cycle.

bleeding" cycle and is used to improve the cycle economy with reasonable capital expenditure. A given amount of steam is extracted at two, three or more points of the turbine and is used for heating the feed water on its way to the boilers, the steam having first done a certain amount of work in passing from the stop valve to the point of bleeding. In this way the remainder of its heat is used to preheat the feedwater instead of being rejected to the circulating water in the condenser.

Reheating, Fig. 7, is really a method of reducing the moisture in the turbine exhaust and if adopted is used with turbines operating at 600 p.s.i and over. The turbine may be made up of two independent units or alternatively as a tandem set which is standard for ordinary working. The steam from the high pressure turbine is returned to a reheat boiler for temperature raising or resuperheating and then delivered to the low-pressure turbine and expanded down to condenser pressure. The advantages claimed for the reheat cycle are : higher thermal efficiency ; reduced feed pump power ; smaller condenser ; smaller boiler and less fuel handling and firing equipment.

It is usual to employ a combination of regenerative and reheating

cycles to obtain maximum economy with given temperature and pressure limits.

The use of high pressure topping turbine sets, Fig. 8, has been more or less restricted to the improvement of the heat rate of

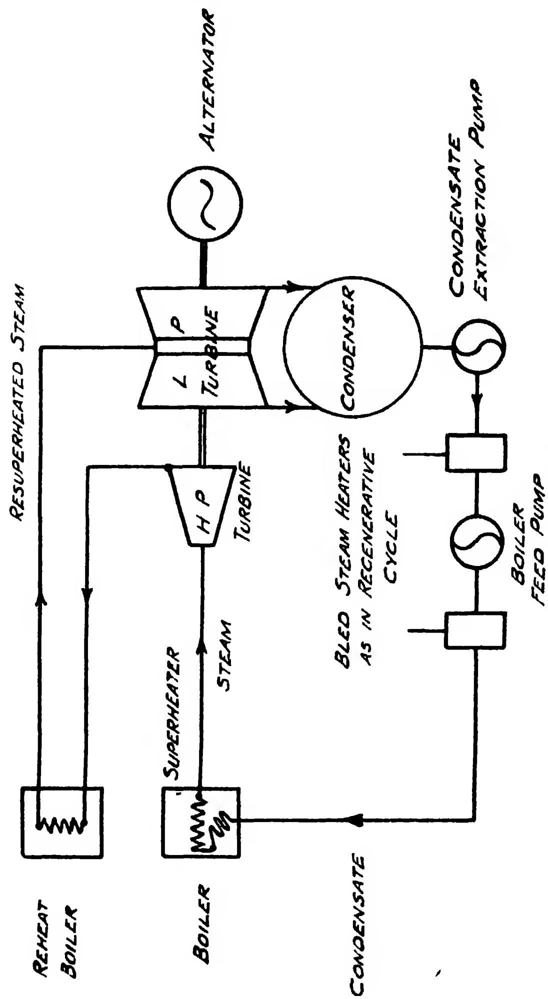


Fig. 7. Reheating Cycle.

existing stations. The superimposing of a small high-pressure turbine is a practical proposition and the added capacity is obtained with reasonable capital and running costs. The high-pressure turbine operates non-condensing, and exhausts into the low-pressure steam range by way of a reheater for use on the low-pressure turbines.

ing range of temperature. There is a boiler in which the mercury is vaporised at a pressure of 113 p.s.i.g. and a temperature of 945° F. for driving a 15 MW turbo-alternator at 720 r.p.m. A condenser associated with one boiler enables the heat given up by the condensing mercury to be employed for converting water into steam at the rate of 200,000 lb. per hr. at 400 p.s.i., 700° F., for driving

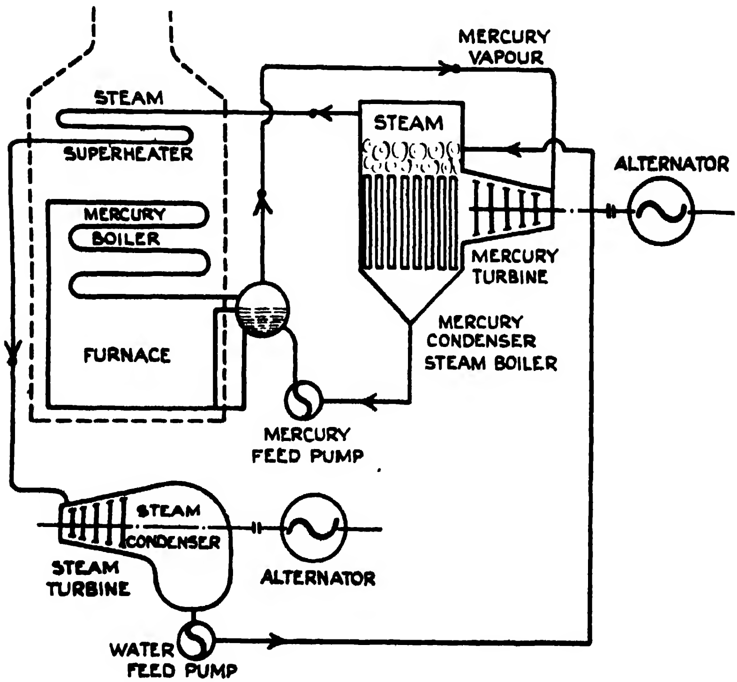


FIG. 10. Mercury-vapour-steam-electric Generating System.

existing turbo-alternators. The binary system is more economical thermally than either a mercury or a water system but introduces other complications.

Mercury-steam plants of relatively small outputs are capable of providing electrical power at materially lower fuel rates per kWh. than steam plants of like capacity. In a paper published in *Mechanical Engineering*, July, 1951 (H. N. Hackett), it is stated that there are numerous types of applications where this cycle may be used to advantage, but most applications come under four general types, as follows :

(1) Complete condensing plants where only electrical power is produced, suggested nominal plant capacities would cover the range of from 12·5 to

130 MW with expected fuel input rates of 10,500 B.Th.U. to some 8,800 B.Th.U. per net kWh. from the smaller to the larger sizes.

(2) Topping plants for topping existing steam plants where (*a*) additional electrical generating capacity is required in addition to supplying high-pressure steam to existing steam turbines ; (*b*) additional electrical power and process steam is required for factory process work or for supplying low-pressure steam for central heating systems, and electrical power for general distribution.

(3) Mercury-plant installations where an acute shortage of important facilities exists, such as (*a*) deficiency of condensing water ; (*b*) insufficient steam-boiler capacity and demand for electrical generating capacity.

(4) For the rehabilitation of otherwise obsolete steam-generating plants where (*a*) inefficient or obsolete and defunct steam boilers require replacement ; (*b*) where it is desired to increase the overall power plant efficiency to the maximum : (*c*) where it is desired to increase the plant efficiency and at the same time add the maximum amount of topping capacity.

Diphenyl-oxide has been suggested instead of mercury. It is an organic liquid which boils at 496° F. under atmospheric pressure, equal to saturated steam at 680 lb. p.s.i with a vapour 94 times as heavy as steam. The cost is considerably less than mercury and is claimed to be non-poisonous and not decomposed by heat or prolonged boiling.

The choice of any one of the cycles outlined is generally speaking an economical one, and the factors involved are : capital and operating costs, thermal efficiency obtainable, price of coal and the load factor of the station.

Combinations embodying cycles 1 and 2, also 1 and 3, are to be found in British power station practice, whilst cycle 4 has been occasionally employed in some stations abroad. For stations of 10–500 MW capacity it is common practice to use the regenerative cycle with steam pressures up to 650 p.s.i., although there are exceptions, and in these are often to be found either the reheating or high-pressure superimposed cycles.

CHOICE OF STEAM PRESSURE AND TEMPERATURE

The trend is towards higher pressures and temperatures, and if our engineering industry is to keep pace with advances made elsewhere it is essential that it should have opportunities for making similar progress, otherwise its competitive powers will be greatly reduced.

The problem of deciding upon the steam pressure and temperature to be adopted is an economic one, Figs. 11 and 12. In considering the merits of increase in pressure and temperature on overall efficiency it will be seen that whilst the former obeys the law of diminishing returns, the latter gives an almost straight line law, indicating the

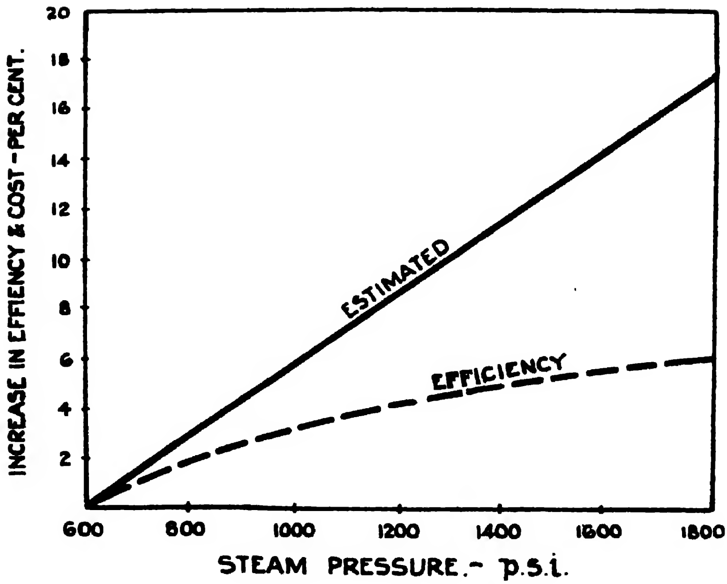


FIG. 11. Effects of Increased Steam Pressure.

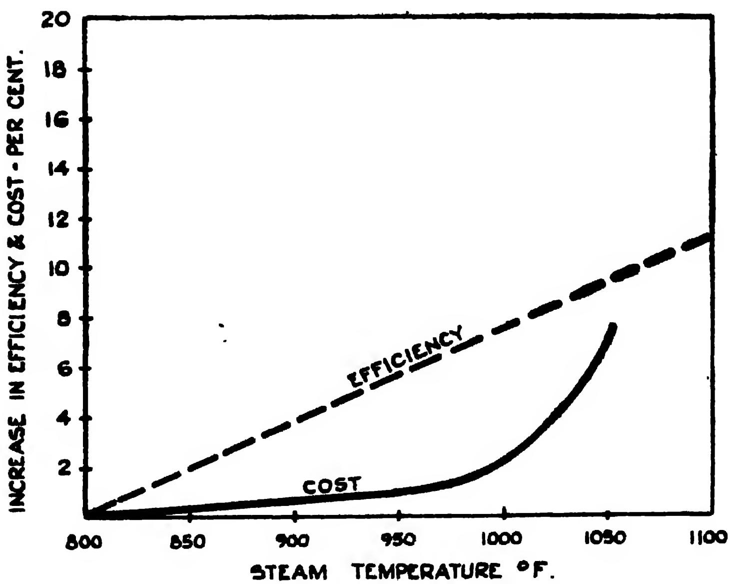


FIG. 12. Effects of Increased Steam Temperature.

desirability of adopting the highest possible steam temperature. The degree of superheat must be decreased as the pressure increases so as to keep within the required limit of total temperature. The limit of the adoption of very high temperatures is the strength of the available materials, and after 900° F. is reached the problem becomes rather complicated because the change in the physical properties is so rapid that it cannot be allowed for in design alone, Fig. 13.

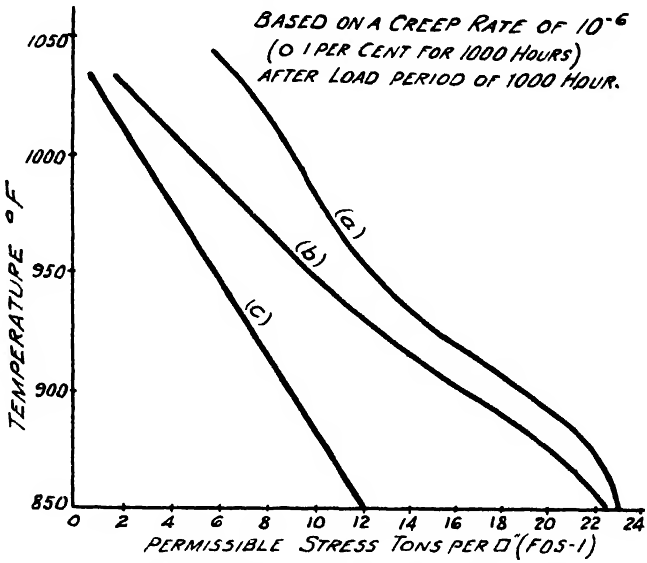


FIG. 13. Typical Creep Strengths of High Temperature—High Tensile Steels.

Creep strength is the ability to withstand applied stresses whilst undergoing physical changes due to high temperature. At temperatures above 700° F. steel will yield continuously and this deformation is termed creep.

Steel (*a*). Has very high creep strength. Used for boiler drums, turbine casings, superheater headers and tubes, valve bodies, etc., mild carbon molybdenum steel.
Steel (*b*). Chromium molybdenum steel. Used for steam flange bolts, etc., where strength during the cold condition is desired.
Steel (*c*). Less highly alloyed steel than (*a*).

One leading authority recommends a minimum factor of safety of 3 on the yield stress and suggests the following as permissible creep rates :—

Turbine discs, 10^{-9}, turbine cylinders, bolted flanges, 10^{-8}; steam piping, boiler tubes, 10^{-7}; superheater tubes, 10^{-6} (0·1 per cent for 1,000 hours).

Molybdenum improves creep and embrittlement of high-temperature steels; silicon improves the corrosion resistance of chrome-molybdenum alloy, which is also relatively immune from graphitisation.

Boilers have been built to generate steam at a pressure of 3,220 p.s.i. (706° F. saturation temperature) which is the critical pressure, being that at which the densities of water and steam are equal and therefore at which the water passes into steam without ebullition.

Above this temperature the water vapour becomes a true gas—that is, it cannot be liquified whatever pressure be applied to it. At the critical pressure the latent heat becomes zero, the specific volumes (before and after formation) are the same.

Before the steam is applied to the turbine it is throttled to about

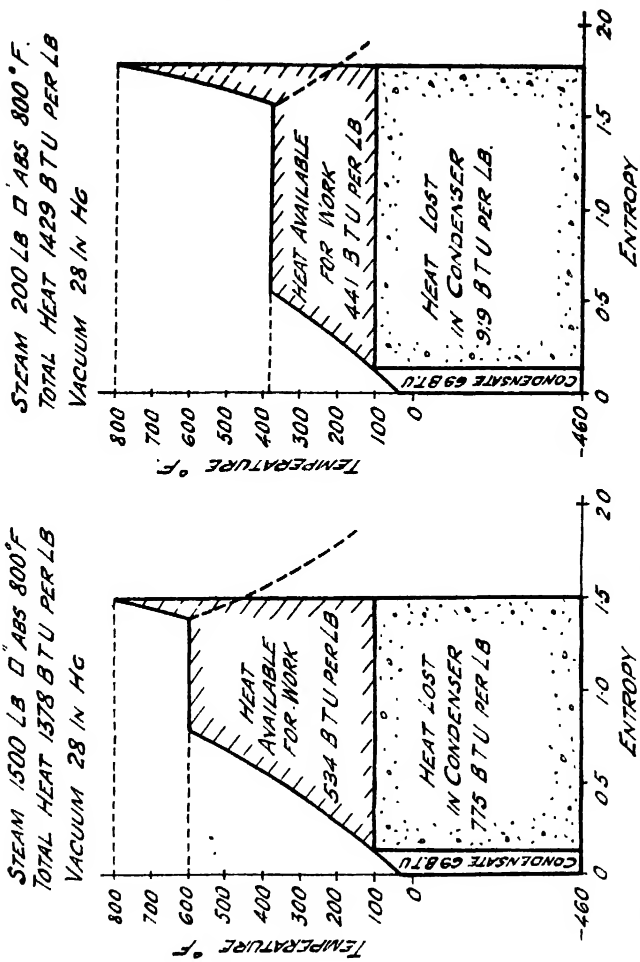


Fig. 14. Temperature-Entropy Diagrams comparing heat available for work with steam at 1,500 and 200 p.s.i.

1,500 p.s.i. and superheated to 800° F. The reason for this is that steam at 3,000 p.s.i., dry saturated when expanded adiabatically down to about 29 in. Hg, contains almost 50 per cent. of moisture.

In considering the economy which theoretically may result from the use of higher steam pressures, a reference to the temperature

entropy diagrams, Fig. 14, is useful. Entropy is the ratio of the heat content to the temperature of the body, *i.e.*, $\frac{\text{Total Heat}}{\text{Total Temperature}}$ It will be observed that the heat available for work at 1,500 p.s.i. is

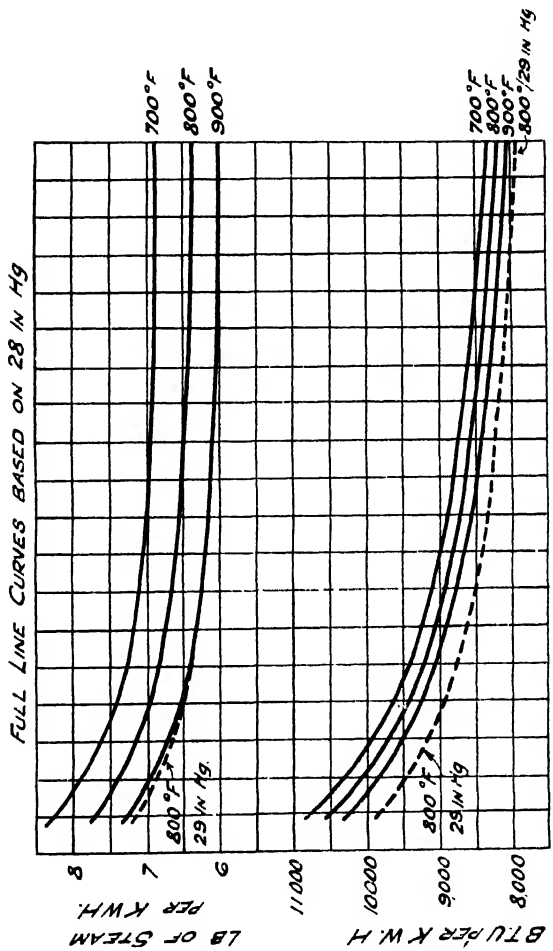


FIG. 15. Curves showing Effect of Steam Pressure on Theoretical Steam and Heat Consumption.

534 B.Th.U., or 1·2 times the heat available at 200 p.s.i., which is 441 B.Th.U. The diagrams show that at the higher pressure the total heat in one pound of steam is 3·57 per cent. less than at the lower pressure but, on the other hand, the heat available for work is 21 per cent. greater. They also indicate the large proportion of heat which is rejected to the condenser compared with the heat available for work,

and it is for the purpose of still further reducing the amount of heat rejected to the condenser that regenerative feed heating schemes have been developed.

Fig. 15 shows the theoretical steam and heat consumptions at various initial steam pressures and temperatures and clearly indicates the increases in efficiency which may be obtained as steam pressures and temperatures are raised.

From the curves in Fig. 15 further curves (Fig. 16) are produced illustrating the percentage rate of decrease in heat consumption with steam at various pressures. It will be observed that the

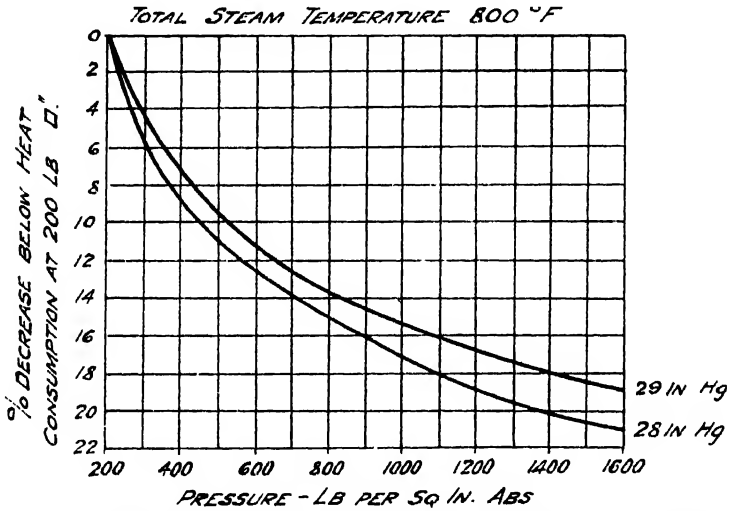


FIG. 16. Curves showing theoretical Decrease in Heat Consumption obtained by Increased Steam Pressure.

percentage decrease is slightly higher when the steam is expanded to 28 in. Hg. than when it is expanded to 29 in. Hg, from which it follows that the adoption of higher steam pressures is even more advantageous to stations operating with cooling towers than those at which ample supplies of cold water are available.

It would appear that present practice favours the use of steam pressures in the neighbourhood of 900 p.s.i. for entirely new stations, but that there is a profitable field for higher pressures of the order of 1,500 p.s.i., when the problem is that of increasing the thermal efficiency of existing medium-pressure stations. The alternative would be the complete replacement of the whole of the existing plant including both boilers and turbines. A proved pressure and temperature may be adopted in view of very rapid growth of load for it may

be imperative that a new station should be put into commercial operation as soon as possible. By the time this was accomplished the load would be such that outages should be reduced to an absolute minimum. Such circumstances do arise during normal conditions but are more frequent during wars. Under these conditions it is not advisable to attempt anything in the nature of experiment and a pressure and temperature should be adopted and plant installed which are known to be satisfactory as the result of previous experience. Investigations which have been made show that a 100 MW turbo-alternator under certain conditions of fuel prices provides adequate return on the capital and running charges when operating at 1,200 p.s.i., 950° F. as compared with 650 p.s.i., 850° F.

The design of generating plant in the future will depend in no small way on the metallurgist in that new materials will have to be produced to meet the demands of engineers.

In cases where fuel costs are excessive and load factors high it may be justifiable to adopt a rather higher steam pressure as a small gain in overall efficiency would be of relatively greater importance. Whilst the efficiency of generation is an all important factor in station design, and more so where fuel costs are on the increase, sight should not be lost of the numerous other factors such as reliability, repairs and maintenance charges, simplicity of operation, space occupied and capital cost.

The main features to be considered in fixing the initial steam conditions are: the capital cost of the plant, thermal efficiency realisable, price of coal, and the load factor of the station. The time element may be a controllong factor in design and the more important sections of plant may be chosen from proved designs in order to expedite delivery, erection and commissioning and also ensure reliable operation.

For many years numerous coal mines have been dumping large quantities of small (duff) coal to waste, and some power stations have been designed to take advantage of this cheap fuel. Such stations are in general not designed for high thermal efficiency but have proved a commercial proposition.

It would appear that the time must cóme when the valuable constituents of coal which are now wasted by the ordinary methods of boiler firing will be extracted and used to better advantage.

CHOICE OF VOLTAGE OF GENERATION

As with steam pressure and temperature the choice of voltage of generation is chiefly an economic one, although much will depend

upon local conditions. The space available may not be adequate to accommodate step-up transformers, and the question of switch-gear rupturing and current carrying capacity also have to be borne in mind. There is also the fire risk at the station, which is of particular value from an air raid precaution standpoint.

Fewer circuit breakers, cables and outgoing feeders are necessitated when generating direct at say 20 kV or 33 kV thereby effecting considerable savings in buildings and site area. Circuit breakers operate under improved current conditions and better use is made of the cable conductors since skin and proximity effects impair current-carrying capacity in the larger sizes. The size and cost of cables affects the choice of voltage as cables become very cumbersome when large powers have to be handled at lower voltages. The number of large section single core cables that have to be used in parallel per phase result in high costs due to the space and supporting arrangements required also the increased handling during installation.

In the choice of voltage of generation and switching due regard must be paid to the sizes of circuit breakers available. At the present time the following have been suggested as standard maximum values in this country :—

Working kV	Rupturing Capacity MVA	Current Rating Amps.
6·6	350	1,600
11·0	500	2,000
22·0	1,000	1,600
33·0	1,500	1,200
66·0	2,500	1,200
132·0	3,500	600
275·0	7,500	600

A large base load station transmitting power over long distances may have a feeder voltage of 132 kV., in which case step-up transformers would still be required, and it may therefore be more economical to instal lower voltage alternators.

The highest generating voltage in use at the present time is 36 kV., and this has proved satisfactory. In the very near future it is quite possible that alternators will be put into commercial service operating at 66 kV. If a reasonable proportion of the load in a station be at 33 kV. then there would be some justification for installing high voltage alternators.

The trend in large undertakings is to transmit at 33 kV. to suitable distribution centres throughout the system and then step-down as required to suit the area served.

Experience indicates that it is better to deal with the rapid growth of load by the use of higher grade insulation than by heavier conductors.

STATION OPERATION

Referring to Fig. 3 it will be observed that the load varies throughout the day in which case certain plant will have to be shut down and started up almost every day. Such operating conditions are usual in any power station, but when designing a new station it is essential to know whether it will be required to run as a one-, two- or three-shift station, and possibility of interconnection with other stations, if the most suitable types and sizes of plant are to be installed.

If a one- or two-shift station is visualised some of the factors to be kept in mind are :—

(1) The effect on boiler plant efficiency, availability, banking and starting, also load response. The choking and corrosion of air heaters and economisers resulting in increased maintenance and repairs. Steel chimney and gas duct corrosion is also aggravated.
(2) The effect on turbine efficiency--low loads for extended periods. Daily starting up and shutting down necessitating the provision of motor-driven turning gear.
(3) Steam and feed pipe ranges are subject to frequent temperature changes which are conducive to joint failure and so reduce the availability of the plant served.
(4) Increased boiler make-up water has to be provided for.

The fundamental principle of any large interconnected electrical system such as the National Grid is to bring about a saving in the costs of generation, to afford greater protection against interruption of supply—*i.e.*, increased reliability of supply—and to permit of centralised collection of cost and other statistics together with co-ordination of policy and planning of future development.

Power stations as mentioned above may be classified into three principal groups, namely, Base Load, Secondary, Seasonal.

The thermal efficiency of base-load stations is high due to the fact that a steady load of high-load factor is always guaranteed, which justifies the use of high-efficiency plant. This allows plant to operate under good conditions since frequent starting and stopping is eliminated.

Repairs and maintenance charges may generally be higher than for other classes of stations due to the temperature and other conditions which obtain. The total station costs are lower because a larger number of units can be generated at high thermal efficiency and the operating costs, such as salaries and wages, are spread over a greater number of units.

Secondary stations usually operate more economically through interconnection due to the fact that they can be shut down instead of running at low and uneconomic loads. Centralised control enables these plants to be run at predicted loads over longer periods and not necessarily follow the variation of the particular local load which may be available. The thermal efficiency should be slightly improved and repairs and maintenance charges will be about the same. The shutting down of plant during the night usually allows of a more effective maintenance programme, but in practice conditions may differ so much that no hard and fast rules can be applied. On the whole the total cost of production would not vary very much from those applying without interconnection, but in many cases there should be some overall improvement.

Seasonal stations are required for peak loads, and therefore operate for short periods at variable loads and the thermal efficiency is low. The operating cost in respect of salaries and wages is high per unit generated and the total cost of production of such a station, due to interconnection, is generally higher. Interconnection makes it possible for the controlling authority to determine the areas of load growth and plan the plant extensions to give the best economic return. It can also take advantage of the latest advances in thermal and electrical power plant practice obtaining and collate the effects of these on design construction and operation.

The selection of sites for power stations is one of the major problems in post-war planning, and as finality in design is never reached it is hoped that improvement will continue as knowledge of materials and other factors increases.

CHAPTER II

CIVIL ENGINEERING WORKS AND BUILDINGS

Site. In considering the site for any new power station it is necessary to take account of its make-up and general contour. Riverside sites are often on alluvial flats, and it is essential to ascertain the nature of the substrata and their ability to carry heavy concentrated loads. A good bed of stiff clay, marl or compact gravel, providing there is no underlying stratum of sand or peat, should make a suitable foundation. Where alluvial mud or sand predominates it is usually necessary to drive piles into the underlying subsoil and to float the site with a concrete raft.

The geology of the locality may be extremely complicated and indicate tremendous disturbances combined with extraordinary dislocation of previous well-formed strata, the strata probably being almost vertical. An examination of the proposed site by survey and borings should be made to ascertain its suitability for the erection of an electric power station. The nature of the subsoil can be found by digging pits and sinking borings. The following soil mechanics methods have been used in the design of one large station :—

(1) The ultimate bearing pressure of a cohesive soil is $5{\cdot}5 \times$ shear strength of soil.

(2) The active and passive pressure on walls built in clay soils were calculated by the $\theta = 0$ method, using immediate shear strength value in conjunction with Bell's formula.

(3) Blum's graphical method was used for determining the bending moments in sheet pile walls.

Where the choice of site is limited and excavations and borings indicate unsatisfactory conditions, that is, the site is very poor for the purpose of foundations, then piling will have to be resorted to. Such a procedure is costly but may be justified by other advantages gained by using such a site.

Particulars of two sites are given, the first being that where piled foundations were unnecessary and the second where this type of foundation had to be used.

Site 1.

(*a*) A layer of stiff clay, 6 ft. thick.

(*b*) A firm layer of sand and gravel, 16 ft. thick. Water is found about 12 ft. below the surface which roughly corresponds to the river level.

(*c*) Stiff blue clays and shales, almost as hard as rock, onwards.

Site 2.

(*a*) Above ordnance datum the ground consists chiefly of ashes and mud with a little clay and soil.

(*b*) Below ordnance datum to approximately – 30 ordnance datum the composition is largely of sand and silt.

(*c*) The first good stratum occurs at a depth varying from about – 30 ordnance datum to – 40 ordnance datum, and consists of a bed of ballast varying in thickness between 6 ft. and 12 ft. Below the ballast is a stratum of brown clay.

The site in the latter case is very poor for the purpose of the construction of engineering works which make up a power station, for at no point can the ground itself be relied upon to sustain any pressure. Every foundation was piled down to the stratum of ballast at – 30 ordnance datum.

Another station site was chiefly marsh land of which some 40 acres was filled in around the buildings by dredging the river. Raft construction (4ft. 4 in. thick) was adopted, being supported on concrete piles driven some 65 ft. to the rock bed. The large area of surrounding marsh provided unlimited space for ash disposal.

The subsoil throughout the site of another station was of alluvial sands and gravel overlying the lower magnesian limestone, which lies non-comformably on the coal measures. Such alluvials are incapable of carrying heavy loads and the foundations of the plant and buildings were extended by piles to the limestone bed. In the initial stages precast reinforced concrete piles were used; the average length of the piles being 35 ft., but in later stages piles varying in length from 30 to 50 ft. were required.

The subsoil of another site (Fig. 29), as might be expected in the basin of a large slow-flowing river, consists of a series of clays and silts of medium to soft consistency, incapable of supporting without considerable settlement loads greater than about ½ ton per sq. ft., whereas the estimated load distribution was about 1½ tons per sq. ft. Examination of bore-hole cores showed no satisfactory stratum existed on which bearing piles could be supported. The principle adopted for the foundation, therefore, was to "float" the foundations in the surrounding earth. The whole area of main buildings was excavated to a depth of 22 ft. 6 in. and a cellular reinforced concrete raft built into the excavation. In the turbine house the deck of the raft had to be omitted to provide for the condensing plant; and to preserve the continuity in the raft the floor was made considerably thicker. The sections of the station on the two rafts are completely separated by an expansion joint and will remain so even when the rafts themselves are joined.

Another site consists of alluvial soil (mud) washed down from the hinterland and in places is over 40 ft. deep. It is incapable of supporting the weight of the buildings and plant, and it was decided to provide a mass concrete raft 500 × 248 ft., varying in depth from 15 to 30 ft., to take the boiler house, turbine house and transformer annexe. The total weight of this single block is about 150,000 tons. Two rings of sheet steel piling were driven to enable the mud to be excavated to provide room for pouring the concrete raft.

There are two other items which should be considered when selecting a site, namely, the possibility of flooding by the river, and mining rights.

As regards flooding, it is often possible to have access to records held by the river authorities over a considerable period, and reference can also be made to ordnance maps. In any case provision can be made in the design and construction of the station so that a few feet of water will not endanger its working.

The fixing of the station datum line requires attention so that the water level of the circulating water system (be it sea, river or lake, and especially tidal rivers or estuaries), is used to full advantage in saving pumping power. The levels of spring and ebb tides and of flood levels determine the levels of the circulating water system, coal jetty and turbine house. Cooling tower stations also depend very much on site conditions since it is possible to use a combination of both pipe and concrete culverts for the circulating water.

The question of mining rights should be given careful consideration, and it is always advisable to seek the opinion of a mineral surveyor on matters of this nature. These rights may be held by private companies, who may compel the station owners to buy the coal at an exhorbitant price by threat of working after the heavy buildings are erected. In some cases they are unable to work them both from financial and geological considerations.

The site area required for an electric power station depends on the amount of plant to be accommodated. The price of land varies considerably, as will be observed from the following :—

London area	£40,000 per acre.
Provincial area	£50 to £100 per acre.

It is difficult to give any reliable figures for plant installed on power-station sites, for on considering a number of stations it was found that the acreage varied from 8 to 150 and the MW installed from about 5 to 50 per acre.

The following information relates to a 300 MW riverside station using sea-going colliers and pulverised fuel firing :—

	Acres.
Main buildings	5·22
Switch house	0·64
Transformer park	0·26
Workshops, stores, etc.	0·60
Coal—Storage area	4·35
Ash— „ „	0·40
Subsidiary buildings, roads, railways, jetty and cranes	7·43
TOTAL	18·90

Coal storage	125,000 tons (45,000 under water)
Ash „	4,000 „

Throughout the detailed design of a station a careful check should be kept on the building volume and floor space for the various sections of plant, otherwise the preliminary estimate costs may be exceeded. Where excavation is costly, due to the presence of hard rock or to loose alluvial soil which necessitates the use of sheet steel lining, the floor area should be reduced to the absolute minimum consistent with reliable and efficient operation. It may be necessary to provide approach roads and cable tunnels for some considerable distance outside the station and allowance should be made for these items.

Types of Ground. The first step is to determine the nature and properties of the ground, and in some instances the nature of the ground may be known to be sound locally by the stability of existing or previous structures. If there is any doubt as to the exact nature of the ground it is essential to investigate its character not only to the depth of the foundations, but considerably deeper.

These investigations may be carried out in various ways, such as :—

(*a*) Probing. (*b*) Test pits and shafts. (*c*) Borings. (*d*) Exploratory tube. (*e*) Test pile.

The probing test is carried out on shallow foundations for it is simple and cheap. Hollow steel rods—1½ to 2 in. internal diameter in 8 ft. lengths—are screwed together to make up long lengths. A pointed steel toe and steel driving head are screwed to the bottom and top of the rods (Fig. 17). The rods are driven by striking with a heavy hammer or mallet, being rotated at the same time by a tiller clamped to the rods. The bar is driven until it enters hard ground which is noted by the resistance to driving and the " feel " of the rod.

Probing to a depth of 10 ft. in compact material and 20 ft. in soft ground is usual, the whole area being covered.

Test pits about 5 ft. square are used for inspecting and testing the strata for shallow foundations.

To test for bearing value a set-up as shown in Fig. 18 is used. A graph showing the settlement plotted against load is drawn and the "yield point" of the ground may be taken as the point at which the slope of the graph changes (Fig. 19). The safe bearing pressure for foundation design may be taken as about one-half the pressure at the yield point of the ground. Borings may be made in

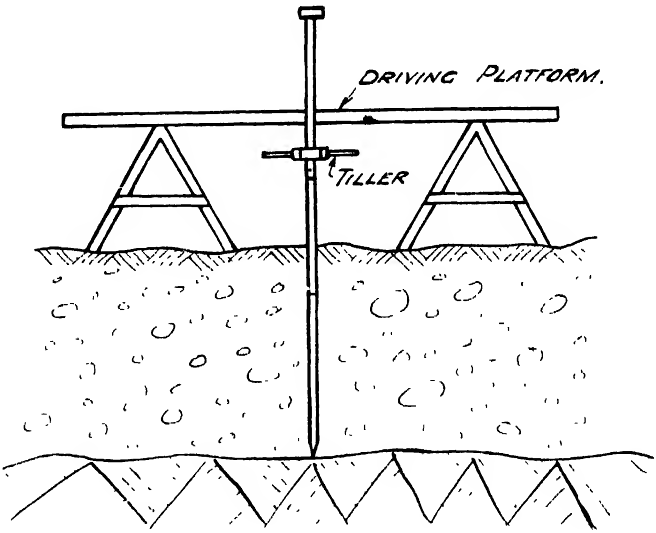


FIG. 17. Probing Equipment.

several ways—percussive boring and rotary boring. The former consists of penetrating the ground by a series of blows delivered continuously from cutting tools of reasonable weight for the job in hand. The resulting broken materials (samples) are removed as desired, by a sludge pump. Fig. 20 shows this method as used for hard boring. Boreholes are formed by using 6-in. diameter tubes or, in difficult conditions, 8-in. diameter tubes for the upper section. Holes may be bored to a depth of up to 50 ft. or more below ground level. A boring log-sheet is recorded for each hole giving the surface level, depth of borehole, the thickness of every stratum met with and artesian water levels. Exploratory tube methods are borings of about 16 in. diameter. The large outer tube,

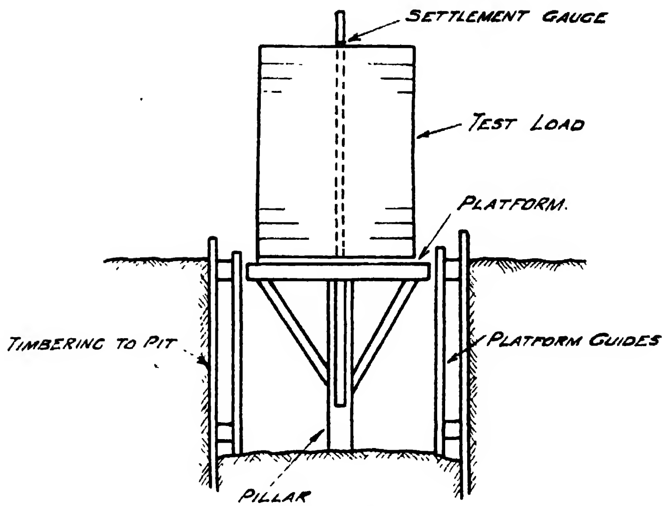


FIG. 18. Test for Bearing Value of Ground.

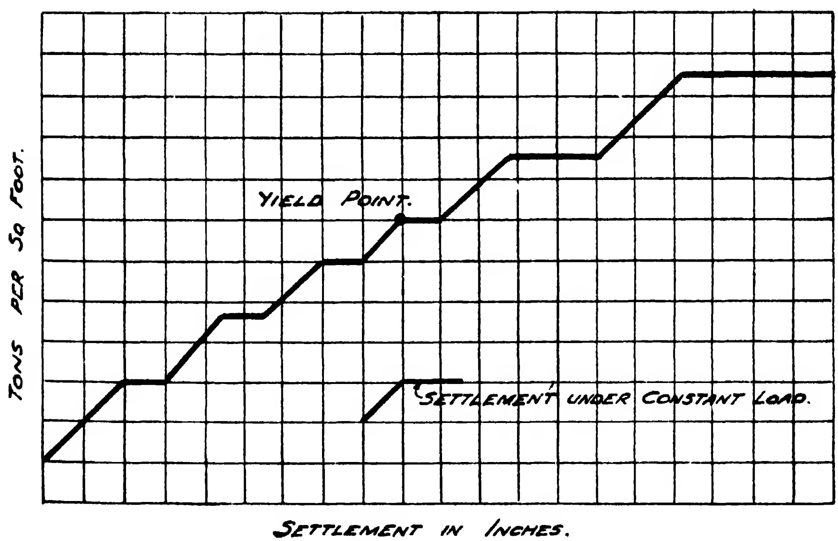


FIG. 19. Load Settlement Graph.

Fig. 21, is sunk to the required depth as in borings and the internal tube (about 10 in. dia.) carries the test load. The internal tube has a steel foot at the base of 1 sq. ft. area and a test platform at the top. The maximum depth at which such tests may be carried out is about

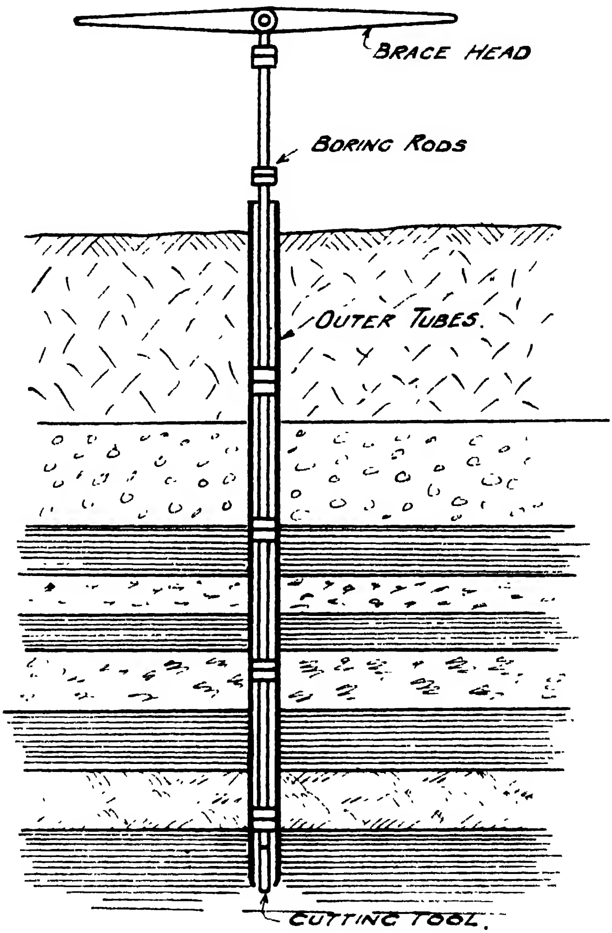


FIG. 20. Arrangement for Percussive Boring.

50 ft. Test piles provide information regarding load-carrying capacity by either friction on the side of the pile or bearing on the pile toe or a combination of both.

As a guide in the design of foundations, the safe loads given in Tables 2 and 3 for various materials may be used. It will be observed

that clay cannot be relied upon. If it is dry and in thick beds it forms a good foundation, but if wet it becomes lubricated and plastic, having little bearing value and less shear value.

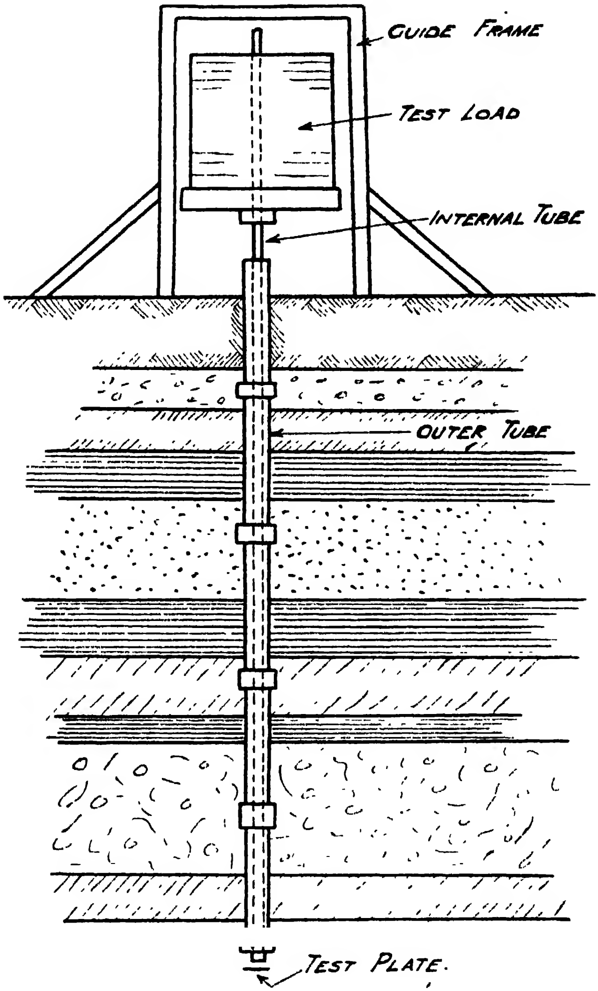


FIG. 21. Exploratory Tube Set-up.

It is particularly dangerous if alternately wet and dry, as it shrinks on drying. In one station the ground consisted chiefly of red stone, and a bearing pressure of 9 to 10 tons per sq. ft. was allowed.

Foundations. Having briefly outlined the site and ground conditions, the next problem is that of foundations.

TABLE 2. *Safe Bearing Loads on Sub-soils*

Sub-soils	Maximum Safe Pressure in tons per square foot
Alluvial soil and quicksand	less than $\frac{1}{4}$
Chalk—Soft	$\frac{3}{4}$
,, —Hard	3
Sand—Dry	1
,, —Fine and very compact	3
,, —Firm, enclosed by sheet piling	6
Clay—Moist, soft	$\frac{3}{4}$
,, —Yellow, dry	2
,, —London blue	4
,, —Boulder, dry in thick beds	5
,, —Wet in thin layers inclined	0
Gravel—Ordinary	3
,, —Compact	4
Rock—Soft sandstone, limestone, etc.	2
,, —Medium, Yorkstone, Gritstone, Blue limestone	8
,, —Hard in thick layers—granite, etc.	30–75

For machinery and structures, these must fulfil some or all of the following requirements :—

(1) To maintain the machinery and structures rigid and keep all parts in true alignment.

(2) To transmit the dead weight of the machinery and structures to the ground and distribute it in such a manner that the safe bearing pressure of the ground is not exceeded. This dead load always acts vertically downwards.

TABLE 3. *Safe Bearing Loads on Foundation Materials*

Materials	Maximum Safe Pressure in Tons per Square Foot
Granite	20–30
Limestone	15–20
Sandstone	12–15
Portland Stone	12–20
Blue brick in cement mortar	12–15
Red brick in cement mortar	4–6
Red brick in ordinary mortar	2–3
Concrete 1 : 2 : 4	10
Concrete 1 : 3 : 6	6

(3) To transmit if required the live loads of the machinery and structures

to the ground. The directions in which the forces act, due to the live loads, will depend upon the types of machinery and structures used.

(4) To absorb as far as possible vibrations set up by machinery so as to transmit as little as possible of this vibration to the surrounding ground. The machinery foundations should be isolated from the building foundations to reduce the transmission of vibrational forces to a minimum and obviate

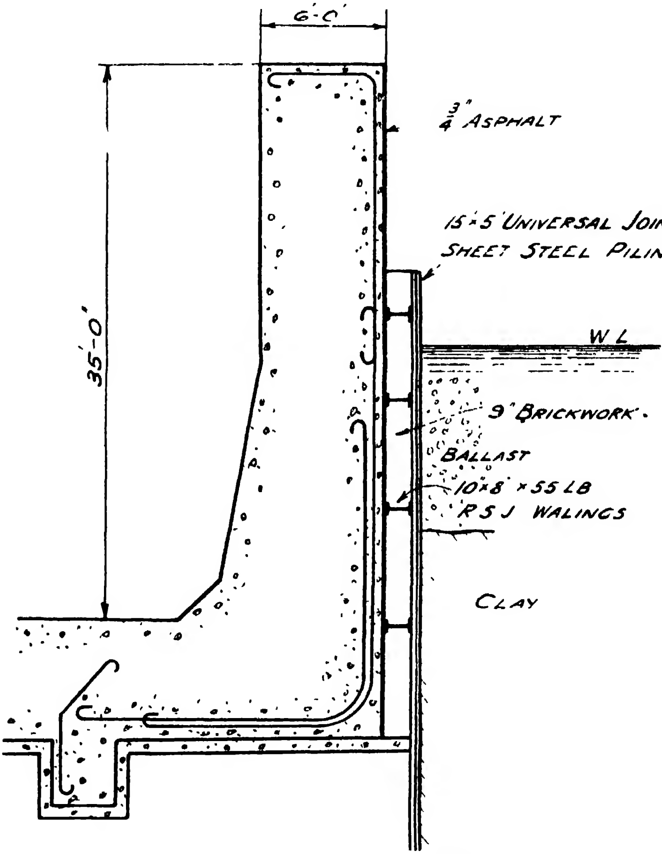


Fig. 22. Retaining Wall Section.

troubles due to settlement. A foundation should be heavy enough to take care of any accidental out-of-balance forces which may arise during normal working of the machinery.

The designs and types of foundations will depend primarily on the subsoil obtaining on the site, and it is necessary to determine the nature of the subsoil so that the possibility of settlement can be eliminated. The latter may in turn determine the type of building

construction to be adopted. The nature of the ground will also fix the loading per sq. ft. that may be superimposed so as to maintain a reasonable safety factor. Preliminary investigations may indicate the necessity for piling in which case costly preparatory work may be encountered. Site conditions may be such that it is possible to construct a substantial concrete raft over the whole area of the buildings, reinforced at the upper and lower edges. The ducts for the inlet and outlet of the cooling water may also be incorporated in the raft where these ducts are in contact with the buildings.

If the sub-soil has very poor load-carrying abilities then a very light form of building is necessary to keep the loading within prescribed limits. It may be necessary to dig out the ground to get the proper strata upon which to build the foundations and in such cases it is cheaper to form a base ment than to fill it up again. This usually calls for the construction of heavy retaining walls, Figs. 22 and 23, but the alternative would be to fill up to get above water level if the site is in the vicinity of a river; further, it may be necessary to use piled foundations. Under such conditions it may be necessary to carry the whole of the structure and large machinery on a heavy reinforced concrete raft. At one large station the raft was laid on London blue clay at a depth of 30 ft. below ground level, and the stanchion loads were distributed by means of steel grillages so that the pressure on the clay did not exceed 4 tons per square foot. The raft was built in mass concrete with a mix of 6 parts of ballast to 1 part of cement, and had a general thickness of 12 ft. It was constructed in two operations, firstly up to the underside of the main grillages and then by a mass filling to basement floor level.

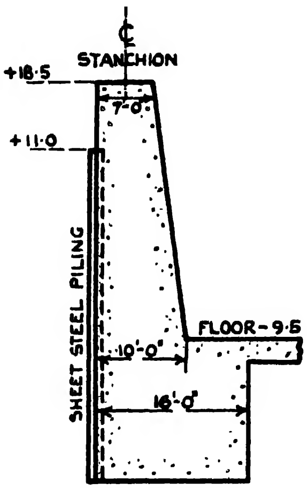


FIG. 23. Mass Concrete Retaining Wall.

In another station it was found essential to use piled foundations —the piling being capped with concrete mats or rafts—and some idea of the work involved in piling will be gathered from the details given.

The foundations for the turbine house main columns on the side away from the boiler house are of reinforced concrete, 9 ft. thick,

24 ft. long and 18 ft. wide. They are each carried on twenty-eight 14 in. square reinforced concrete piles. The foundations for the turbine house main columns on the boiler house side are 27 ft. 6 in.

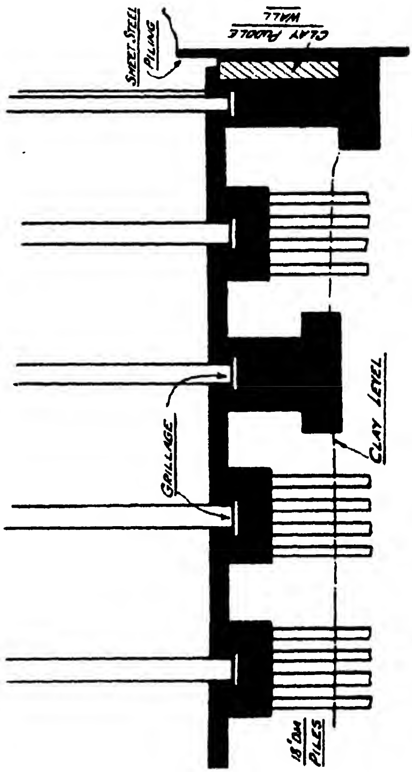
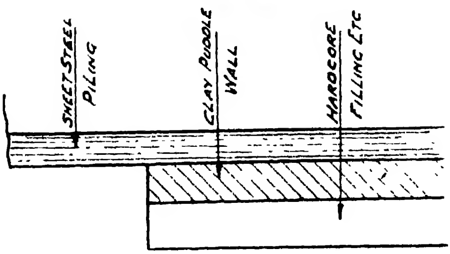


Fig. 24. Piled and Mass Concrete Foundations.



long, 18 ft. wide and 9 ft. deep, carried on thirty-two piles, 14 in. square. In all cases the main column bases have grillages, the grillage and 2 ft. of the column-shaft above the base plate being buried in the concrete foundation. Including piles for four — 50 MW turbo-

alternator blocks, the total number of piles driven in turbine house was 1,606. The total number of reinforced-concrete piles for one boiler house holding eight boilers was 1,387.

Where the ground is reliable it will be found quite suitable to provide a reinforced concrete raft of about 3 ft. to 4 ft. in thickness with $\frac{7}{8}$-in. diameter rods at 12 in. centres, top and bottom. This may appear to be excessive, but it always pays to be on the right side to allow for probable extra loads.

It is possible to get a site where the load-bearing value is low and at such a depth as to make piling impracticable. An example of this was experienced where muddy clay and silty sand extended over depths varying from 70 ft. to 90 ft. below ground level. A cellular reinforced concrete raft construction was used for the boiler and boiler-house foundations to limit the loading on the

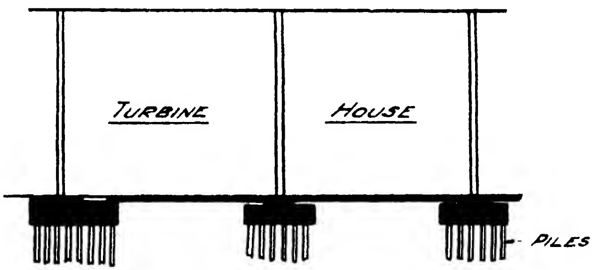


FIG. 25. Piled Foundations for Turbine House.

ground to approximately $1\frac{1}{2}$ tons per square foot. Even so some settlement took place, and records indicated that the structures sunk some $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in. during the first few months without giving trouble. By adopting cellular construction the dead weight is considerably reduced and the stiffness is increased by the inclusion of longitudinal and transverse beams. Such a raft design for boilers of 200,000 lb./hr. M.C.R. output was as follows :—

Total load on any stanchion base . .	720 tons.
Total load carried by raft	13,350 tons.
Bottom slab of raft	18 in. thick.
Top slab of raft (basement) . . .	8 in. thick.
Walls of raft	18 in. to 36 in. thick.

Figs. 24–29 illustrate some typical foundations. One of the largest modern applications of the displacement raft type of foundations is that for the Calcutta Electric Supply Corporation. The ultimate capacity of the station is 210 MW (3–50 MW and 2–30 MW sets).

The power station superstructure, together with the administrative building is carried on a large cellular-type formation raft, Fig. 29, because borings made at site showed the ground to consist of clay and clay silts of poor bearing quality. By going to a depth of 21 ft. (only 4 ft. greater than required for circulating water mains and auxiliaries) and using cellular construction, sufficient displacement could be obtained to reduce the gross bearing pressure to 1½ tons per sq. ft. Soil tests showed that with this value, settlements, although appreciable, would not be objectionable. The overall dimensions of the raft are: width, 229 ft.; depth, 20 ft. 9 in.; length, about 450 ft. The raft provides a means of obtaining the necessary stiffness and strength in bending and shear to spread concentrations of surface loadings over large areas without appreciable flexing and distortion. Its hollow recesses accommodate the 6 ft. diameter circulating water pipes, cables, pipes and auxiliary transformers (see Site, earlier).

Probably the most important plant foundation is that for the turbo-alternator, and features of major importance are :—

(1) Adequate rigidity and generous bearing values on soil.
(2) Reasonable maximum deflection of main supporting beams.
(3) Isolation of foundations reducing possibility of vibrations in building structure.
(4) Allowance for final grouting up of sole-plate shims.
(5) Full allowance for all possible loadings during operating conditions.

The foundation may be either of mass concrete, concrete reinforced in certain directions, or wholly reinforced concrete. The trend in continental countries is to dispense with concrete filling and rely solely on the structural framework for carrying the turbine and alternator. The steelwork is usually ample for supporting the weight of the plant without concrete, but cannot be considered as a substitute for reinforcing bars to tie the various portions of the concrete structure together. With a concrete foundation the hot and cooled air compartments are built into the foundation below the alternator, with the air cooler interposed between them. With steel foundations the air duct work is of steel plate construction. Structural steel framework can be arranged to permit of greater clearance for pipework, etc., than concrete foundations, but care is needed to ensure the requisite stiffness by bracing. To prevent lateral transmission of vibration the foundation blocks are usually isolated from the main floors and, as a further precaution, an air space of ½ in. packed with felt, rubber or pitch, is included around the foundation contours. Due to the requirements of the air-cooling system,

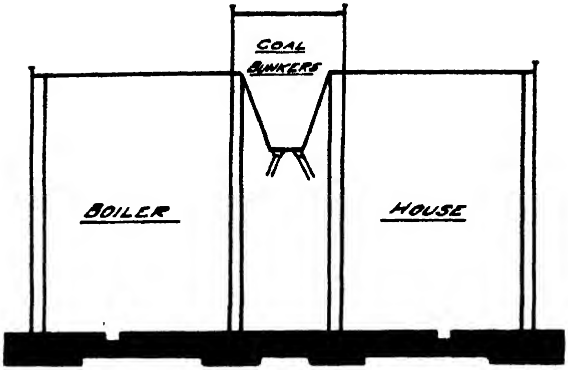


FIG. 26. Raft Foundation for Boiler House.

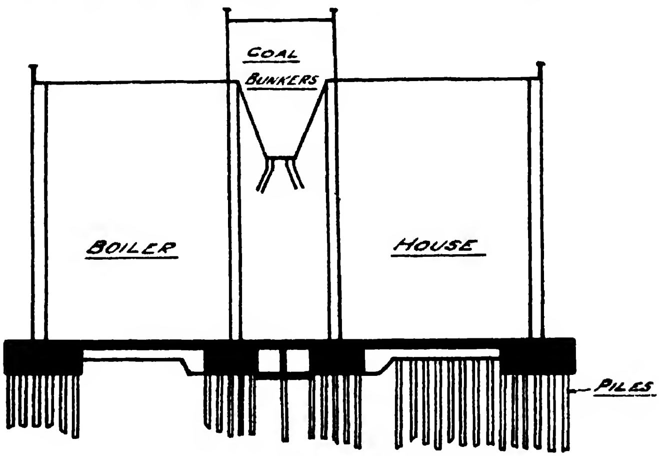


FIG. 27. Piled Foundations for Boiler House.

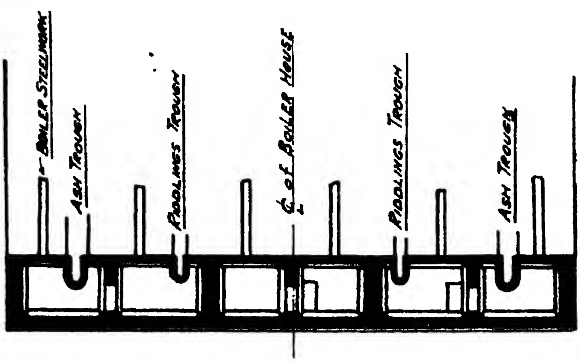


FIG. 28. Cellular Raft Foundation for Boiler House.

it would appear that there is nothing to be gained by omitting the concrete, as the latter may be formed to provide the necessary air circuits for the alternator and it is claimed that the foundations finished in this manner have a better appearance. As so much

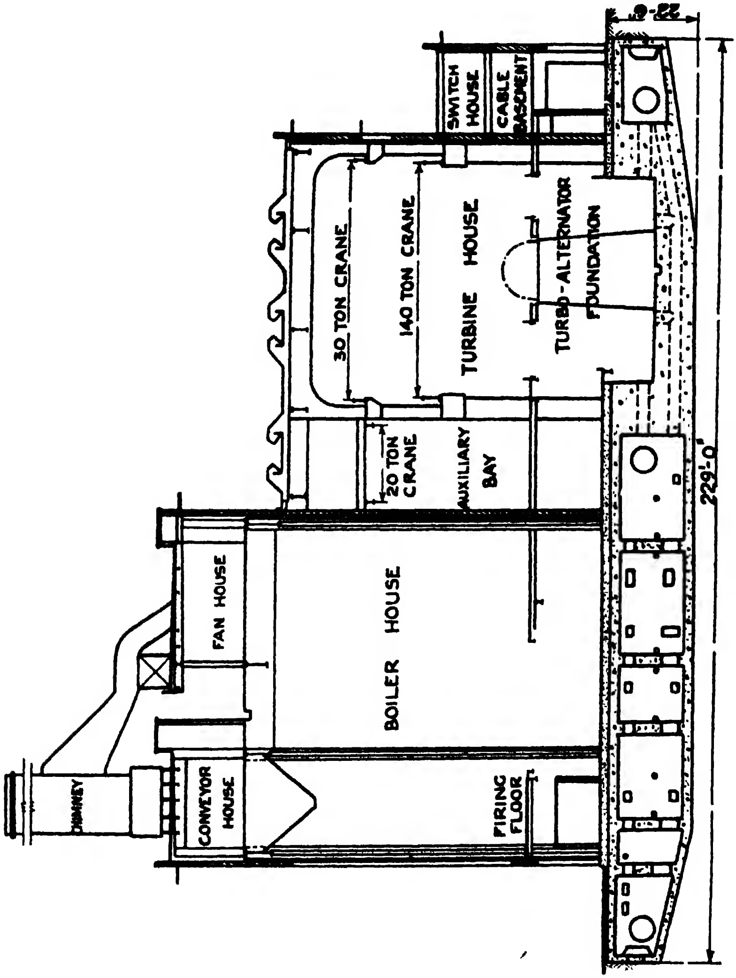


Fig. 29. Cellular Raft Foundation.

depends upon these foundations, the turbo-alternator contractor may recommend that the detailed design be carried out under the supervision of a civil engineer who understands the requirements of such machinery, and that the work be carried out by a civil engineering contractor who has had previous experience of such

work and can be relied upon to make an absolutely jointless monolithic structure. When ordinary Portland cement is used the work should be carried out continuously without any halts. This is most important otherwise there will be a tendency for layers of concrete to form and the final block will not be a homogeneous mass.

If rapid-hardening cement is used the placing should be carried out in sections, so that the heat caused by the hydration of the cement may be adequately dissipated. Failure to do this may cause induced stresses promoting cracking, and the larger the bulk the greater is the tendency for this to take place.

It is sometimes contended that the heat generated by continuous pouring influences setting since a considerable pressure is imposed on the lower portions of the concrete due to the head, the weight of concrete being about 150 lb. per cubic foot. If continuous pouring is not possible, the layers may reach a semi-dry state, which is unsatisfactory for setting when additional weight is imposed by the later layers of concrete. Great care is necessary to ensure that any scum is removed at each tier level before resumption of concreting. With this precaution and the provision of adequate reinforcement considerable intervals can be permitted between pourings although continuous pouring is no doubt better.

Special attention should also be paid to the design and construction of the shuttering, otherwise difficulties may be experienced when pouring continuously because the mass of concrete shrinks during setting.

The shuttering should be stripped according to the provisions made for the setting of the concrete. Time may be gained by the use of rapid hardening cement or the addition of calcium chloride.

The concrete should be composed of cement, sand and aggregate not weaker than 1 : 2 : 4/$\frac{3}{4}$ in. The water should be applied until the mixture is just plastic ($1\frac{1}{2}$ in. slump on a 10-in. slump tester).

The sand should be clean sharp river or crushed sand free from impurities, and should be washed if considered necessary. The aggregate should be clean, sharp broken stone or crushed gravel, perfectly free from soil, clay, etc. Cases are on record where foundation blocks have cracked due to inferior aggregate obtained from a local source. Concrete formed with broken brick will not yield such a high crushing strength as that obtained with the use of the normal aggregate.

The concrete should be deposited in such a way that the surface is always on a slope and any excess water should be allowed to drain

off, and holes in the shuttering will help. The concrete may be compacted by means of mechanical vibrators, but care is necessary to avoid displacement of shuttering and disturbance of partly set concrete.

The concrete should be left some 2 in. to 4 in. low on the alternator block and grouted up after the bedplate is set and packers fitted. The turbine block can be left about 2 in. low at certain points so that the steam chest and pedestal can be grouted up after being set. Probably the best method of fixing the stator is to take the main bolts through the stator feet and soleplate, and anchor on the underside of the main girders or joists. The soleplate is bolted down with independent hard-drawn bolts grouted in and the main bolts are then taken through the stator feet, the soleplate also being grouted in. Bolts can be threaded through the stator feet from the top with the stator in position.

To prevent the breaking away of the outer portions of the blocks it is usual to provide mattresses of reinforcing steel bars, $\frac{5}{8}$ in. diameter bars at 12 in. centres, around the whole of the blocks. The bars should be bound together with pliable iron wire so that the reinforcement is not displaced in the process of depositing the concrete. Figs. 30 and 32 show two typical designs.

The bars usually have from $1\frac{1}{2}$ in. to 2 in. of concrete cover, although $2\frac{1}{2}$ in. to 3 in. has been suggested. Taking a typical 50-MW turbo-alternator set, the foundation consists of two mass-concrete blocks, 80 ft. long overall, 22 ft. wide and 26 ft. high above basement level. A 25-ft. space between the blocks houses the condenser, which is supported on concrete stools poured with and forming part of the main raft. The two blocks are securely tied together at the top by two heavy plate-girders, which support the turbo-alternator. These heavy plate-girders may each be from 12 to 20 tons in weight, and should be unpainted where they are in concrete. As a matter of interest, it may be mentioned that the ends which are set in the turbine block are sometimes given a good coat of varnish to assist movement caused by expansion, and a piece of soft wood inserted between the ends of the steel girders and the concrete takes up any expansion at the steam end. Columns supporting these two plate-girders are carried into the concrete foundations. The blocks are provided with the necessary openings and cavities for air-coolers and fans for the alternator air-circuit and pipework for the turbine. The main girders for one 30-MW set consist of 3-24 in. × $7\frac{1}{2}$ in. 90 lb. R.S.J. with 2-1-in. plates top and bottom, 24 in. wide flush riveted on top and bottom

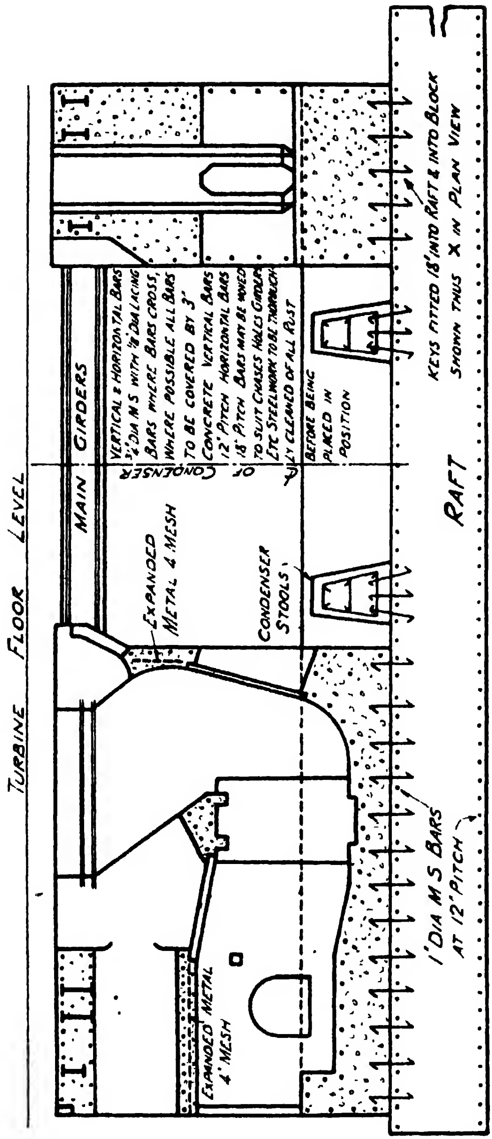


FIG. 30. Turbo-Alternator Foundation. (Sectional elevation.)

in way of double plates and at turbine end. Bolt holes in the girder and certain cleats are elongated $\frac{1}{8}$ in. to allow for expansion of longitudinals in a direction towards the turbine end. The supporting columns are of fabricated angle in box construction, there being two at turbine end, four at alternator end and two R.S.J. columns

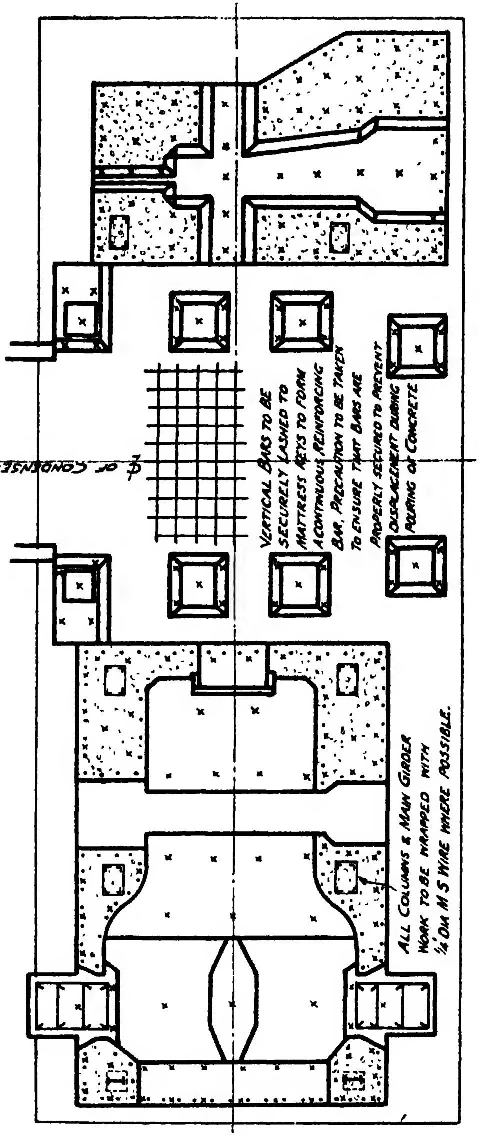


FIG. 31. Turbo-Alternator Foundation (Plan).

at the exciter. Where the steelwork and girders form part of the alternator and exciter air-circuit they are thoroughly cleaned and varnished.

In one example (50-MW set) the machine foundation of two blocks contained approximately 800 cubic yards of concrete. Each

block was poured continuously, the shortest time taken to complete a foundation was three and a half days. The timber shuttering was removed seven days after the final skip of concrete had been poured. Another station having blocks (25 MW sets) each of 400 cubic yards of concrete were poured in one continuous operation lasting about 40 hours. Details of a 30-MW set are given in Table 4 as a guide for much will depend on site conditions.

TABLE 4. *30-MW Turbo-alternator Foundations*

Turbine Block					Alternator Block				
Actual Time for Pouring (Hours)	Concrete (Cubic Yards)	Reinforcing Steel (Tons)	Capacity and No of Concrete Mixers	No. of Men	Actual Time for Pouring (Hours)	Concrete (Cubic Yards)	Reinforcing Steel (Tons)	Capacity and No. of Concrete Mixers	No. of Men
50	170	4	Two 7 cubic ft. each	16	30	120	2·6	Two 7 cubic ft. each	12
Remarks: Timber shuttering removed after 10 days and found in order. Average Turbine House temp. 70° F.					Remarks: Timber shuttering removed after 7 days and found in order. Average Turbine House temp. 70° F.				

To test for settlement of the foundation blocks a number of oil level-gauges may be placed at selected positions around the blocks prior to the erection of the machine. In some cases turbine cylinder distortion has been attributed to settlement of the foundation blocks.

Table 5 gives mixes for various sections of work. Some idea of the loadings in large turbo-alternators will be obtained from the following :—

FOUNDATION LOADINGS

(50 MW, 11 kV, 1,500 r.p.m. set, 600 p.s.i.)

	Tons.
Turbine	220
Condenser	180
Alternator and exciter	160
Short-circuit force	50
Piping and flooring	30
Concrete and steelwork	850
Total load =	1,490 tons.

Total area over which it is loaded = 610 sq. ft.

$$\text{Intensity of loading} = \frac{1,490}{610} = 2\cdot4 \text{ tons per square foot.}$$

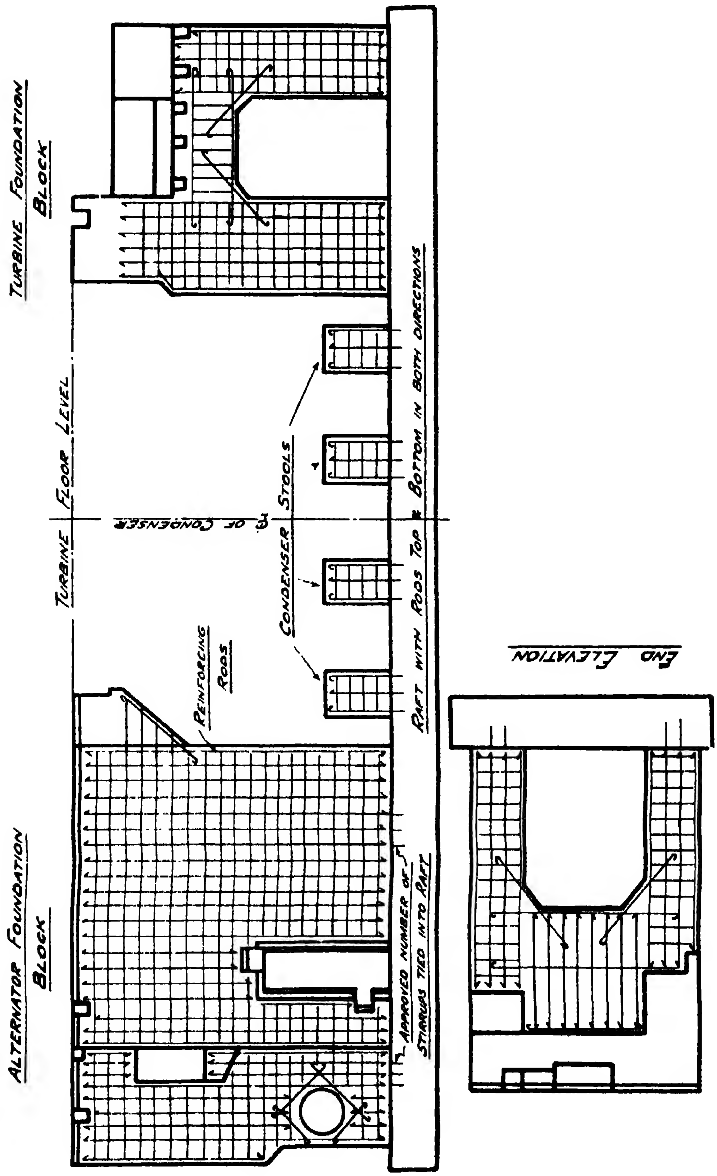


FIG. 32. Elevations of Typical Turbo-Alternator Foundation Blocks.

Maximum intensity of loading = 5·5 tons per square foot (over portions of alternator foundations where short circuit force is acting).

Minimum „ „ = 1·4 tons per square foot (condenser stools).

(30 MW, 33 kV, 3,000 r.p.m. set, 300 p.s.i.)

Alternator block . 425 tons (includes alternator and foundation block).

Area over which this load is distributed = 430 sq. ft.

∴ Load per sq. ft. = 0·99 ton.

Turbine block . . 280 tons (includes turbine and foundation block).

Area over which this load is distributed = 220 sq. ft.

∴ Load per sq. ft. = 1·27 tons.

Condenser stools . 8 stools, total 110 tons (includes condenser with leakage test water).

Area over which load is distributed per stool = 13 sq. ft.

∴ Load per sq. ft. = 0·85 ton.

Mass foundations . 830 tons.

$$\text{Total load on ground} = 425 + 280 + 110 + 830 = 1{,}645 \text{ tons.}$$

Area over which this load is distributed = 1,150 sq. ft. approx.

$$\therefore \text{ Load per sq. ft.} = \frac{1{,}645}{1{,}150} = 1\cdot43 \text{ tons average.}$$

Maximum load per sq. ft. = 1·8 tons.

General particulars of ground for this example are :—

0—8 ft. made-up ground.
8—15 ft. shale with clay and traces of gravel.
Below 15 ft., good gravel.

If provision has to be made for protection from splinters and bomb blast, a 12-in. thick reinforced concrete canopy will afford some protection. Such a canopy will usually consist of some fourteen units, each weighing about 10 tons, although the number and size will be governed by the size of the turbo-alternator. This additional load is fairly well distributed over the turbine and alternator foundation blocks so that the increase per sq. ft. is small.

It is very important that the concrete surfaces of the air circuits should be perfectly uniform, smooth and free from formwork marks and imperfections. The finish should be such that particles of concrete will not become dislodged and carried with the cooling air into the alternator. The faces of the concrete should be left sound and solid, free from voids, and any holes in the surfaces should be filled with cement and sand (1 part cement, 2 parts of fine sand) and rubbed down with carborundum.

Where the cooling air comes in contact with the concrete the

surface should be faced and treated with a vitrifying or petrifying liquid, silicate of soda or other similar solution, to ensure a hard finish and should be painted or enamelled. The external faces of the blocks may be left smooth or brick-marked but in some cases white glazed bricks have been used.

In a number of recent power station extensions it has been deemed advisable on the grounds of economy and restricted choice of sites, etc., to modernise earlier stations. The modernisation of an old station often neccessitates departures from recognised practice and some interesting problems are usually encountered. No hard and fast rules can be laid down, for site conditions and existing plant both have to be taken into consideration.

The foundations for new plant necessitate the removal of old turbo-alternator blocks and these in turn may have supported the turbine house floor and the switchgear control gallery. In one station precautions had to be taken to support this floor and transverse struts were included to prevent any movement before proceeding with demolition work.

The breaking-up of the foundation blocks requires care where delicate relays and other protective apparatus are in the vicinity and in service. Relays are liable to operate if there is undue vibration, and this must be prevented at all costs. One method of breaking up the blocks is to drill 3 in. diameter holes with pneumatic drills and then insert wedge pieces. Hydraulic tools are then placed between the wedges and a small hand pump generating a pressure of about 2,000 lb. per sq. in. is applied which splits the blocks into reasonably large sections without any vibration or undue disturbance.

Another point to be borne in mind is that a station will often be required to operate at normal output throughout the extension period, and care must be exercised to ensure that interference with running plant is reduced to a minimum. Some minor disturbances are inevitable, but these are chiefly in connection with the linking up of the old and new sections and apply more particularly to the steam, water and electrical plant.

In the design of a foundation for an oil engine (house set), static, rotating and reciprocating parts complicate the problem and must be allowed for.

To eliminate noise and vibration from Diesel engine generators in a film studio power house, the foundations are formed of single island rafts of concrete 2 ft. thick set 9 ft. below floor level and covered with a 2½-in. sandwich of "Coresil" cork on which rests a

common concrete block 7 ft. deep, the whole weighing about 1,000 tons. An insulating air space of 9 in. width is left around the foundation.

Templates are employed for setting out accurately the positions of bolt holes for plant foundations, holes being left in the concrete to receive the bolts.

Wooden core-boxes which are greased before placing in position to facilitate removal are fixed before placing the concrete. After setting, the plant is placed in position on steel packers, aligned and trued up, and the bedplate is then grouted up. The plinth is left some 2 to 3 in. low and with a rough surface to take the grout.

Transformer foundations do not present much trouble and the practice is to make use of substantial reinforced concrete rafts wherever possible. A great deal will depend on the site conditions and the size and weight of the transformer units. Where earthquakes have to be allowed for use may be made of anti-earthquake foundations for large units, which are set on rails and comprise concrete blocks at the four corners to prevent overturning during earth tremors. Reference should be made to Chapters XIII and XIV for transformers and switchgear respectively.

TABLE 5. *Concrete Mixes*

Section	Proportion of Concrete by Volume
Turbo-alternator blocks including condenser stools, fan blocks, piles, etc.	1 : 2 : 4/¾ in.
Mass concrete raft under turbo-alternator blocks	1 : 3 · 6/2 in.
Mass concrete in back filling to foundations, trenches and stanchions	1 : 4 : 8/2 in.
Floors, beams, etc.	1 : 2 : 4/¾ in.

Working Stresses. The following data are given as a guide and should only be followed where applicable, for in many installations the by-laws of local authorities have to be adopted. The stresses to be applied to any structure should not exceed the following for dead loads or two-thirds of such figures for live loads.

	Tons.
Safe load per square foot of concrete foundations (1 : 2 : 4)	8 to 10
,, ,, ,, ,, ordinary brickwork	5
,, ,, ,, ,, hard or blue ,,	8 to 10
Maximum tensile or compressive stress in structural steelwork per square inch	5 to 8
Maximum compressive stress on cast iron bearing plates per square inch	8

Maximum compressive stress on hard York stone per square foot	8
Maximum shear stress in mild steel bolts and rivets per square inch	4
Maximum tensile stress in mild steel bolts and rivets per square inch	5
Maximum wind pressure per square foot	30 lb.
Maximum allowance for snow on roof per square foot	6 ,,
,, ,, ,, superimposed load per square foot	30 to 40 ,,

All floors should be designed to withstand the loadings imposed when dismantling the plant. The following figures are typical :—

Boiler house.	
Basement	5 cwts. per square foot super
Firing floor	5 ,, ,, ,, ,, ,,
Fan floor	5 ,, ,, ,, ,, ,,
Platforms	2 ,, ,, ,, ,, ,,
Conveyor floor	1 ,, ,, ,, ,, ,,
Roof	40 lb. ,, ,, ,, ,,
Turbine house.	
Basement	5 cwts. per square foot super
Operating floor	2- 4·5 ,, ,, ,, ,, ,,
Tank floor	2–4 ,, ,, ,, ,, ,,
Roof	40 lb. ,, ,, ,, ,,
Transformer bay area	1·5 tons ,, ,, ,, ,,
Switch house	5 to 10 cwts. ,, ,, ,, ,,
Control room	2 ,, ,, ,, ,, ,,
Motor generator and battery rooms	1 to 2 ,, ,, ,, ,, ,,

Factors of Safety

Reinforced concrete and mass concrete foundations	6
Steelwork subject to live or rolling loads	5
Steelwork subject to dead loads only	4
Temporary structures for erection purposes	4

In addition to the factor of safety of 5 for live loads, full allowance should be made for impact and the live loads should include machinery, cranes, telphers, hoists, conveyors, etc., carrying full specified loads.

Where fans and pumps are placed on upper floors the steelwork may be desiged to take at least twice the load to allow for vibration, which is a serious factor, particularly where two or more fans are operating at different speeds.

Due allowance should be made for stresses induced by pipe supports, anchors, etc., and the conditions obtaining during erection of the plant should be taken into consideration.

Reinforced Concrete, Steelwork, etc. Care should always be taken to ensure that the work is carried out in accordance with the appropriate specifications. The carrying out of certain sections of the work calls for special attention and care, otherwise trouble may arise later. The strength of concrete varies considerably with the amount of water used in mixing, generally the minimum water, *i.e.*, the "stiffest" mix produces the strongest concrete. The most practical test is the slump test :—

Cone formed of 20 gauge galvanised iron, 4 and 8 in. diameter by 12 in. long.

Tamp each 3-in. layer fifteen times with ½-in. diameter rod. Lift when filled and measure slump.

Maximum slump must not be greater than :—

Footings	3 in. slump.
Columns	4 ,, ,,
Floor, walls and beams . . .	5 ,, ,,

The steelwork should be examined for straightness of sections, closeness of joints, faulty rivets and bolts, drifting holes and dimensions. After inspection and before leaving the makers' works, all steelwork should be thoroughly cleaned and coated with either one coat of boiled oil laid on hot or one coat of protective paint to prevent pitting and corrosion. All faces in contact and inaccessible portions should be given one coat of protective paint before erection. After erection, all exposed surfaces should be cleaned down and given at least two coats of paint of approved quality, composition and colour. It is generally accepted that a three-coat system provides good protection, using a primer and a good hard undercoat with a finishing coat which can be varied to suit conditions obtaining. Good results can be obtained under dry conditions by using an aluminium finishing coat, whose reflective powers protect the undercoat from the deleterious effects of light besides being itself resistant to general corrosive effects and also giving a good appearance.

Because of its higher resistance to attack from flue gases high-alumina cement has been used for exposed concrete work, and in mortar for brickwork. Concrete spalling due to freezing of absorbed water may be due to : poorly graded aggregates ; incorrectly proportioned mixes ; excess water ; insufficient mixing ; separation of constituents ; over-manipulation ; poor curing or protection.

The foundation steelwork for a turbo-alternator should be complete with bolts, nuts, washers, cleats and holding bolts, etc., for fitting up on site. Girders, plates, etc., should be perfectly flat, and all holes for rivets and bolts should be drilled and not

punched. Steelwork should have centre lines distinctly marked on to facilitate erection and should be flush riveted and painted where shown.

BOILER STRUCTURAL STEELWORK

Rating.	*Tons.*
100,000 lb. steam per hour	90
200,000 ,, ,, ,, ,,	165
300,000 ,, ,, ,, ,,	225
500,000 ,, ,, ,, ,,	375

TURBO-ALTERNATOR STEELWORK

Rating.	*Tons.*
20 MW	25
30 ,,	30
50 ,,	60
60 ,,	65

These are average figures.

Piles and Piling. Piles for use on power station sites are usually one of four classes, namely :—

(1) Reinforced concrete piles.
(2) Wood piles.
(3) Reinforced concrete pressure piles. (4) Steel piles.

In view of the difficulties experienced in excavation and pumping and the number of foundations required, it may be justifiable to use piles in place of mass concrete blocks. Pile-driving formulas vary for almost all sites, but the Sanders formula has given satisfactory results and is :—

$L = \frac{WH}{8d}$ where L . . safe load in tons.
H . . drop of hammer in inches.
W . . weight of hammer in tons.
d . . set of the pile for the last blow in inches.

Where the ground consists of very soft and unstable material for a considerable depth or where unstable small mass foundations are necessary, it may be safer to use a number of raking piles. These help to stabilise the foundations laterally and are often used under such conditions. Raking piles are usually unnecessary when the buildings are constructed on a heavily reinforced raft of great stability.

The supporting value of a pile is due to the friction on the embedded surface of the pile and the direct pressure at the toe.

If all piles in a group are driven to equal set and the embedded

lengths do not vary much, then it is reasonable to assume they are all equally resistant.

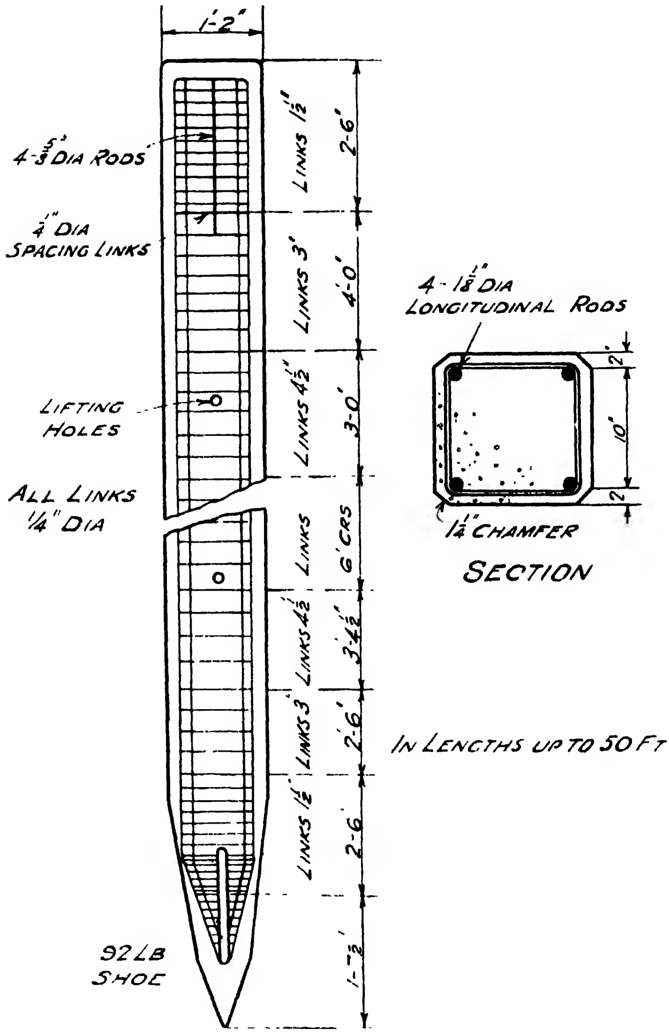


Fig. 33. Reinforced Concrete Pile Details.

Reinforced Concrete Piles. Precast concrete piles are often favoured because of their general superiority in both safety and economy together with their proved reliability over many years. They are very simple in construction and are not subject to patents

or royalties. The piles are normally driven within a week or so of their pouring, but by the use of special cements they can be driven within probably a day after pouring. The foundation is almost ready for full loading immediately and the piles are not damaged by driving other piles alongside. The piles can be driven to a batter or rake when required to take horizontal thrusts. Precast piles may consist of four or six rods $1\frac{1}{8}$ in. diameter, with $\frac{1}{4}$-in. links the pitch of which ranges from $1\frac{1}{2}$-in. centres at shoe and cap to 6-in. centres at the middle. The usual cover is 2 in. of concrete, Fig. 33.

The piles may be of square or round section, probably 14 in. square or 18 in. diameter, and ranging in length from 20 ft. to 50ft., the mixes varying according to the working conditions. An average of fifteen piles have been driven per frame per day.

On one site reinforced concrete piles 10 in. square and in lengths of 16 ft. and 20 ft. were designed for a safe load of 25 tons each and using a 1-ton hammer dropping 3 ft. the piles were to be driven to a set of 8 blows per inch, but in some cases 10 to 12 blows per inch were recorded. The set over the last 8 blows varied from $\frac{1}{2}$ in. to $\frac{3}{4}$ in., or an average of $\frac{3}{32}$ in. per blow. A number of the piles were raked and had a slope of 1 in 40. The concrete was stripped from the piles down to underside of pile caps and reinforcement left projecting 2 ft. and a 2-in. layer of 1 : 3 : 6 mix concrete was placed over the bottom of the holes before the boiler foundation bases were cast.

With sets totalling $\frac{3}{4}$ in. to $1\frac{3}{4}$ in. for the last three blows (14-in. sq. piles), the formula used on one site gave a safe load of from 60 to 40 tons. The average set over the last three blows was about 1 in. or $\frac{1}{3}$ in. per blow, which gave a value of about 48 tons per pile, no pile being loaded to more than 30 tons. Single-acting pile-drivers of 60 and 70 cwt. in frames 60 to 65 ft. high were used for driving the piles. Typical tests on reinforced concrete piles are given :—

Size	Length	Toe level	Hammer weight	Drop	Set per blow	Ultimate resistance
	ft.		tons	ft.	in.	tons
14 in. sq.	45	− 44·2 O.D.	4	4·5	0·5	103·0
16 „ „	50	− 36·5 „	4	4·5	0·1	147·6
16 „ „	60	− 55·4 „	4	4·5	0·2	144·9

Wood Piles. Are used for light foundations such as those required for the stores, workshops and transformers, and are usually

of Oregon pine or pitch pine, the latter being creosoted under a pressure of 80 p.s.i. for 8 hours with not less than 3¼ lb. of creosote per cubic foot of timber.

They are of square section, usually 12 in., ranging in lengths

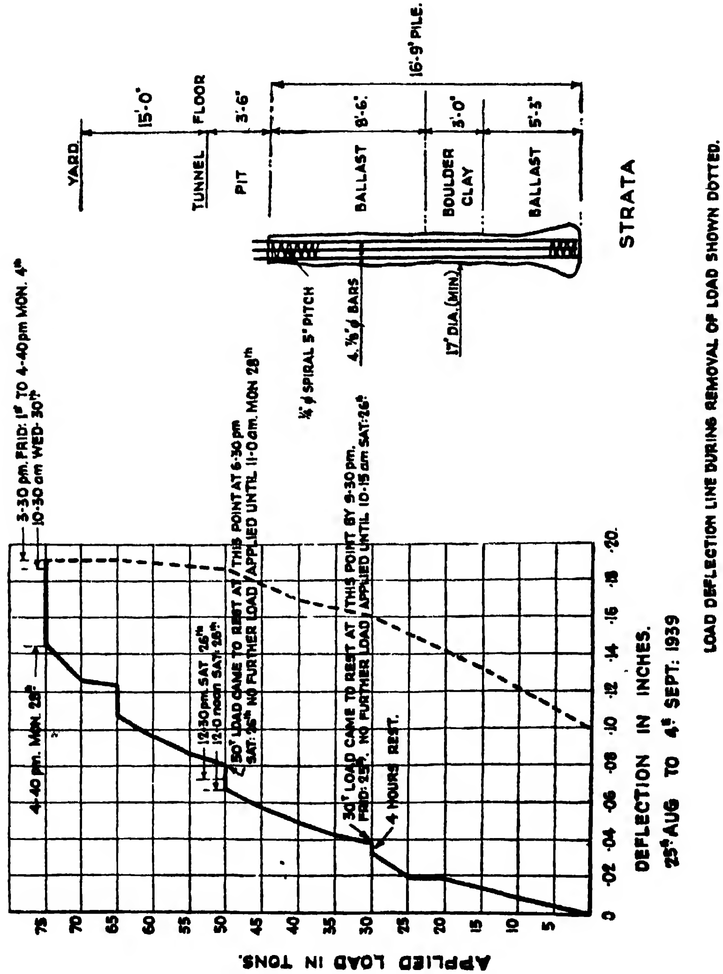


FIG. 34. Test Pile (cast *in-situ* type).

from 20 ft. to 40 ft. A 30-cwt. single-acting steam or compressed air driver may be used for driving these piles and final sets of from ½ in. to 1¾ in. total for the last three blows, with an average of ⅞ in., are usually acceptable. The calculated safe load is from 12 to 40 tons with an average of about 26 tons each.

Pressure Piles. Where piles have to be driven for new foundations adjoining existing buildings the vibration set up may endanger the buildings, and to overcome this reinforced concrete pressure piles may be used. With this system of piling a driver is not required.

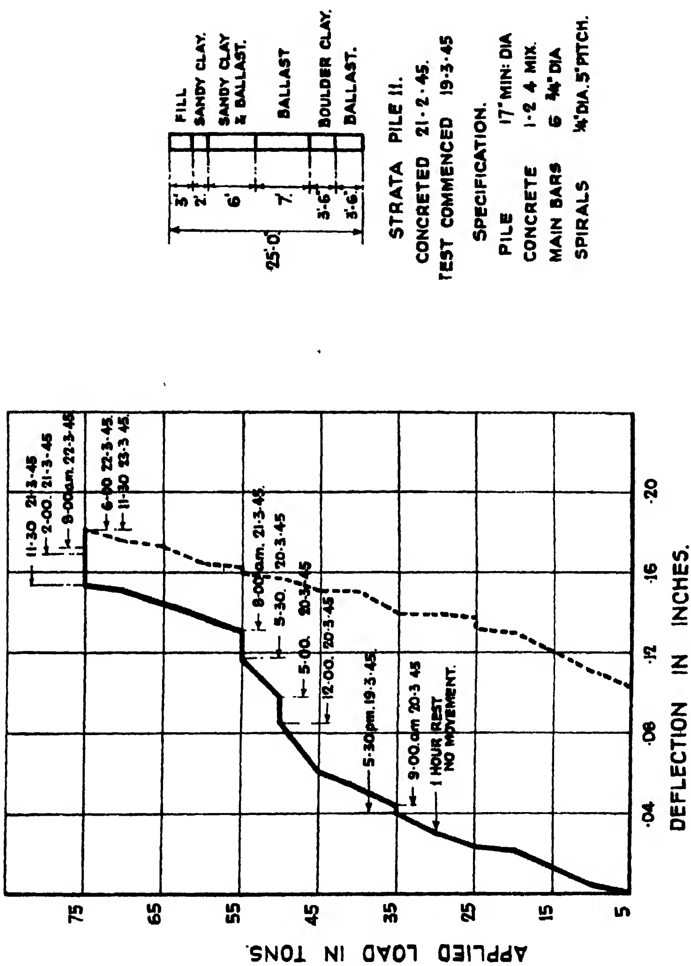


Fig. 35. Pile Test Record (cast *in-situ* type).

The pile used is of the bored *in-situ* type and 17 in. diameter by 16 ft. long units have 6 steel rods, $\frac{3}{4}$ in. diameter, with $\frac{1}{4}$ in. diameter steel wire wound spirally around these rods at 5 in. pitch. Concrete is placed under air pressure and the driving tubes are withdrawn at the same time. Piles of 12 in. diameter having six rods 1 in. diameter

with ¼ in. diameter helicals at 3 in. pitch and up to 45 ft. in length are frequently used. A hole is bored in the ground to the required depth and lined with a steel casing. The skeleton pile is formed by threading a series of short precast perforated concrete discs on to a central steel tube each disc being bedded on to the one below with a rich mixture of cement grout. Longitudinal reinforcing bars are introduced through holes in the discs and the skeleton pile is lowered gradually into the casing. When the full depth is reached the casing is gradually withdrawn, grout is forced under pressure through the central tube and subsoil water is expelled by the grout.

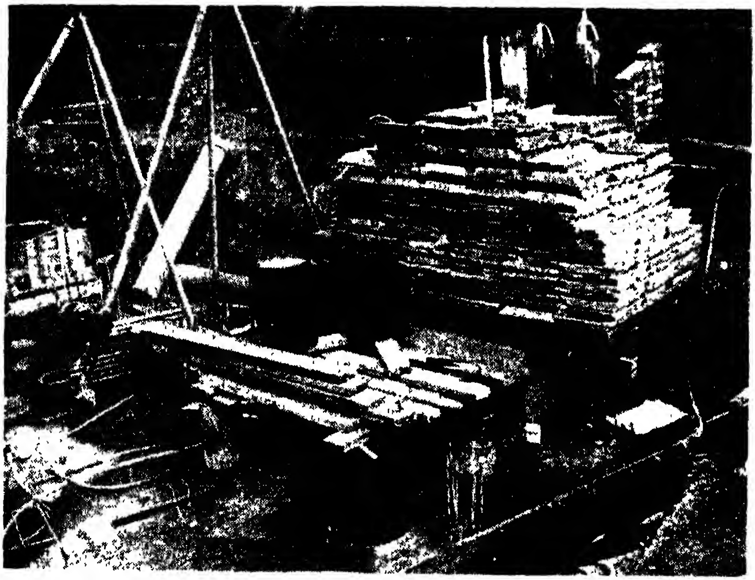


FIG. 36. Pile under Test Load.

In this way all voids are filled and the precast units become a sold pile surrounded with a thick covering of grout. The "Vibro" type piles have been used for buildings, turbo-alternators and high voltage substation foundations. Such piles are specially suited to carry heavy loads and a pile of 17 in. diameter will carry a load of 50 tons. A steel tube casing fitted with a detachable point is driven to the required depth and the steel reinforcement is placed in position ready for introduction of the concrete. As the steel tube is slowly withdrawn by a series of upward percussive blows, a cavity is left into which the concrete flows. In this way a reinforced concrete column is formed.

Figs. 34–37 show pile test data, test loading and deflection indicator.

Steel Piles are generally used during the construction period in the form of H sections for sheet steel piling and are usually of a

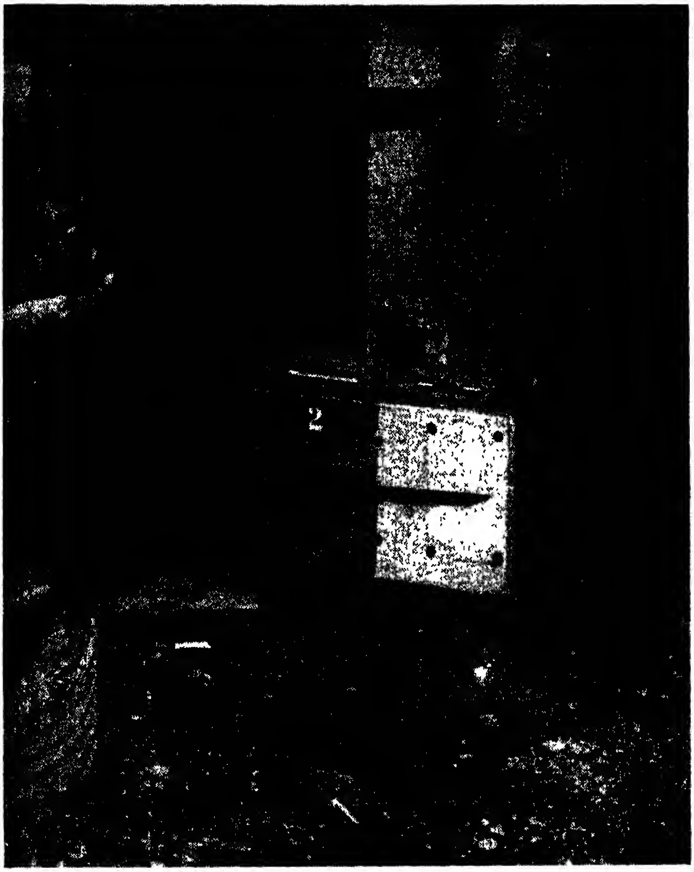


FIG. 37. Pile Deflection Indicator.

temporary nature although they have been used on hard foundations at some considerable depth. Buildings have been supported on steel H piles, 10 in. × 42 lb. sections, driven 50 ft. below ground level. They are particularly suitable for hard driving conditions where there is a hard slag filling near the surface and probably a layer of gravel immediately above rock.

Pre-stressed Concrete. The new field offered by the application of pre-stressed construction, in which the reinforcement is stressed by a permanent and carefully regulated tensile load prior to the application of the working load, will produce economies by utilising high-tensile steel wire reinforcement and will further reduce cross-sectional area and weight. The aim is to relieve the concrete of all tensile stresses and to eliminate cracks through which air can penetrate to the reinforcement and so cause deterioration of the steel. Cracks, so common in reinforced concrete, are avoided because pre-stressing substitutes a degree of decompression when loadings apply in tension.

BUILDINGS

The buildings required for an electric power station and its operation are :—

(1) Turbine house.
(2) Boiler house.
(3) Switch house.
(4) Pump house.
(5) Workshops and stores.
(6) Offices and messrooms.
(7) Laboratory.
(8) Garage and cycle park.

General Arrangement. The arrangement of these buildings will primarily depend upon the site available and the anticipated ultimate output of the station. It appears that the most economical layout would be obtained by having the boiler, turbine and switch houses all adjoining each other for in this way high pressure steam and feed pipe lines and cables are kept as short as possible.

A popular layout for river stations is the placing of the boiler house between the pump house and the turbine house, the intervening space being used as a coal store.

There seems to be no reason why the boiler house and turbine house should not adjoin, but to minimise the risk of fire it is preferable to house the switchgear in an entirely separate building. The pump house is usually placed near the river, but in some stations large water culverts are brought close up to the turbine house and the pumps occupy a bay in this building. With cooling tower stations the latter arrangement of pumps is also quite common. Although the workshops, stores and offices should be kept quite separate from the main buildings, they should not be placed too far away. Offices and outdoor switching and transforming stations

should be kept away from cooling towers and if possible be situated on the side of the prevailing wind. In some cases it may be advantageous to have the workshop so placed that direct access is possible

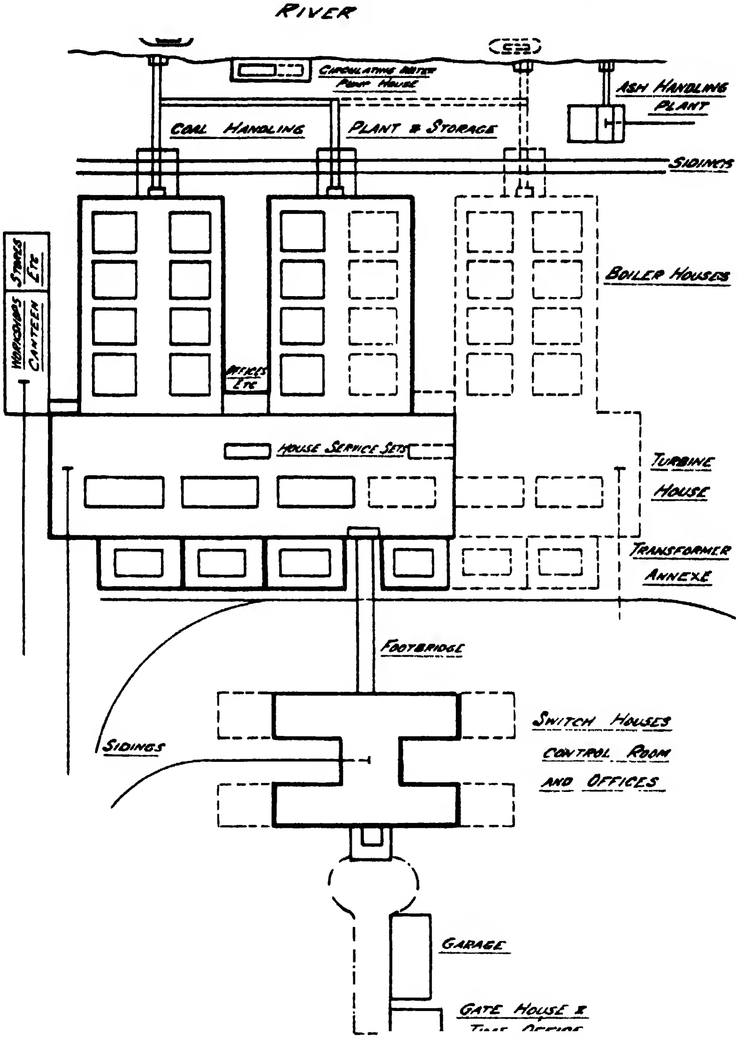


FIG. 38. Layout of 300 MW Riverside Station.

from the turbine house loading bay, as this facilitates handling of plant under repair.

By adopting this layout fire risks are obviated and an independent structure (not necessarily so substantially built as the main

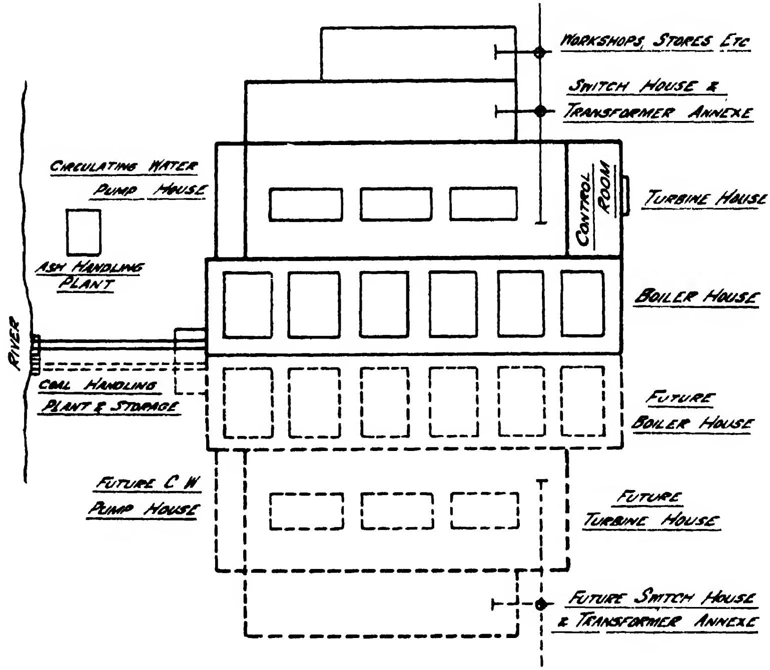


FIG. 39. Alternative Layout of 300 MW Riverside Station.

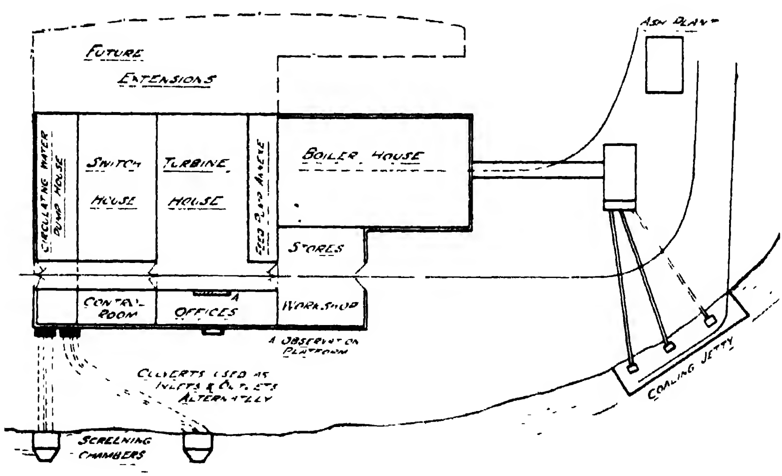


FIG 40. Layout of Station with Duplicate Screening Plant.

buildings) can be used. Apart from the main buildings there is the planning of subsidiary buildings which add to the efficiency and welfare of the employees. Where the offices adjoin the main buildings it may be necessary to have the time office some distance away from the station, when it can also serve as a gate-house.

If possible, the stores should adjoin the workshops, and provision be made for easy access from either the main road entrance or the sidings.

The administration offices should be located in a position having ready access to the turbine and boiler houses, control room, clerical

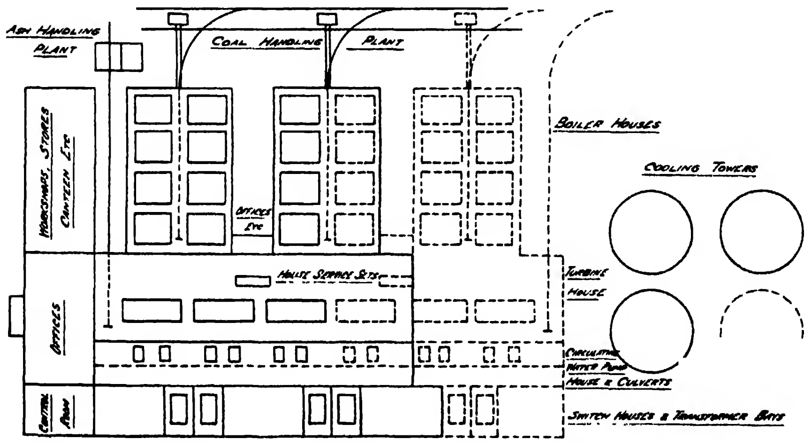


FIG. 41. Layout of 300 MW Cooling Tower Station.

and records offices. The office block, laboratory, storerooms and workshop may be housed in a bay immediately above the feed pump bay between the boiler and turbine houses.

The station auxiliary switchgear and transformers can be accommodated between the boiler and turbine houses, but a great deal will depend on the site available and the capacity of the station. The buildings can be arranged in many ways and when deciding upon their positions the following should be considered :—

(1) Ease and completeness of erection of buildings.

(2) Ease of extension of buildings.

(3) Facilities for transport of plant to and from their respective buildings. This applies particularly to the transport of equipment from the stores to the workshop and from both to the main buildings.

(4) Where possible the switch houses should run parallel to the longitudinal axis of the turbine house and to ensure economy in cabling the switchgear should be placed as close as possible to the generating plant, consideration

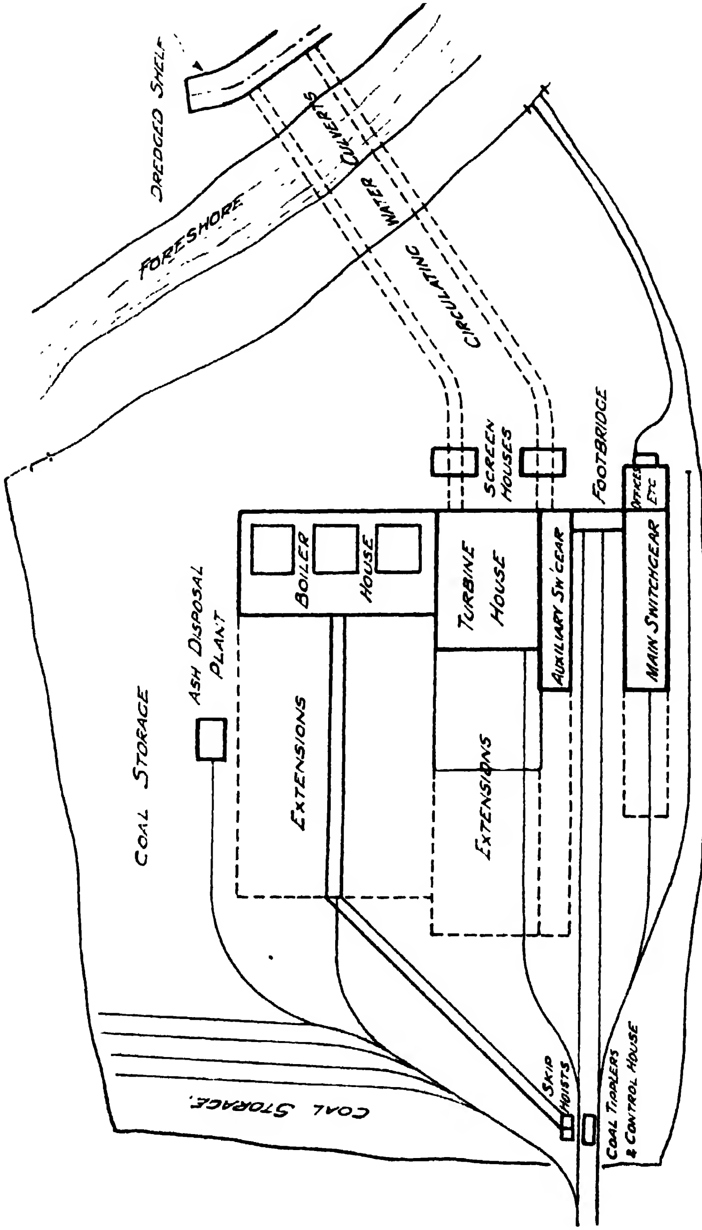


FIG. 42. Layout of Riverside Station.

at the same time being given to the space required for extension to either or both. In large capacity stations where the number of feeders is considerably greater than the number of generators, the tendency is to erect separate feeder switch houses. This segregates the switchgear and minimises dislocation of services due to fire or damage from enemy aircraft.

(5) The positions should be chosen so as to assist in the efficient operation of the station as a complete unit. The trend in power station design is towards a complete unit system, but in all cases a high degree of flexibility is absolutely essential. In the construction of a new station adequate road and rail access should be provided and wherever possible the designs should incorporate

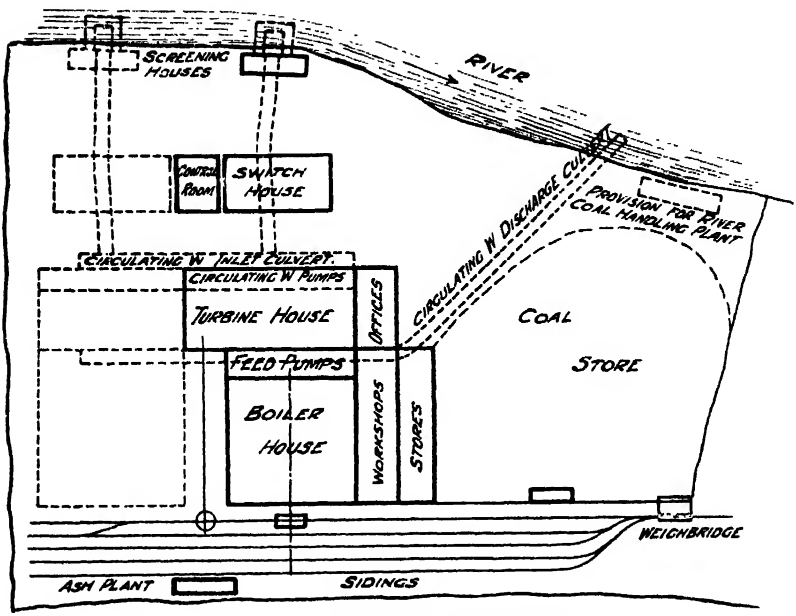


FIG. 43. Layout of Riverside Station.

items of plant which will not only prove useful for the normal operation of the station, but more so during the construction period. These will enable considerable economy to be effected in the cost of constructing the buildings due to a great saving of time.

(6) The direction of the prevailing wind may also be worth some consideration, especially when reviewing possible layouts of cooling towers and more particularly the coal and ash-handling plants.

(7) The station datum-line has to be fixed and this in turn depends on site conditions. Levels of spring and ebb tides, also flood levels, all require careful attention.

Figs. 38 to 44 indicate possible layouts. To obtain some idea of the arrangement of buildings it is an advantage to construct a small

wood model of the site and buildings say, to a scale of 1 in. = 32 ft., as shown in Fig. 45.

Type of Building. The foundations and superstructure of all buildings are designed in accordance with the local building Acts, and in some cases these requirements have involved considerable additional expenditure.

Materials to be employed in the construction of the buildings should be such that an economical and substantial structure is

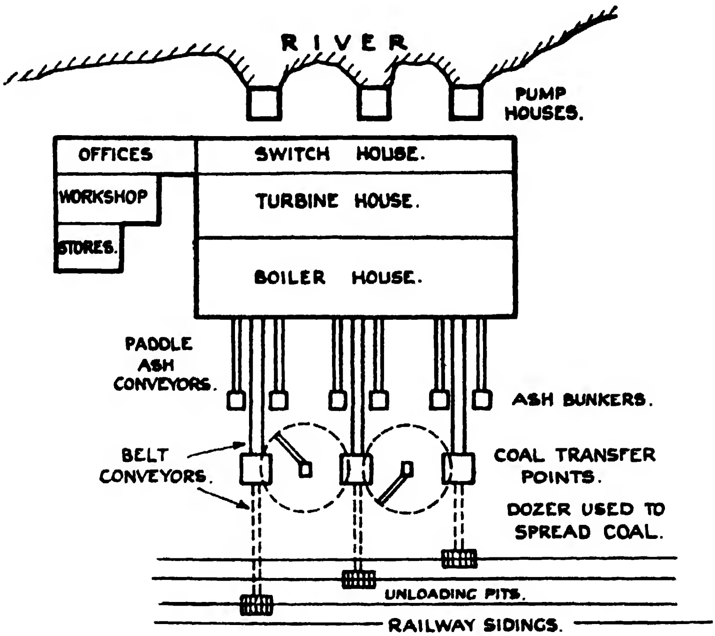


Fig. 44. Layout of 200-MW Riverside Station.

obtained. The buildings should comply in all respects with the Factory and Workshops Acts. The primary function of the buildings is to house the generating plant as cheaply as possible. In some stations attempts have been made to provide pleasing architectural features which have resulted in greater capital expenditure and in no way enhanced the reliability of supply or reduced the running costs. However, it is usually well worth while if the structural expression of a power station is developed in sympathy with the plant it protects although it may entail increased capital cost. Considerable expenditure is sometimes necessary on architectural features such as stone facings or ornamental stone and moulded work to make the

structure harmonise with the surrounding buildings and thus not detract from the amenities of the district in which it is built. Power stations have been referred to as "cathedrals of the electrons," and from the accompanying illustrations it will be agreed that many of them fully deserve this title.

The materials most commonly used are brick, concrete, protected metal sheeting and patent glazing with wire-woven glass.

A simple straightforward treatment of the elevations is probably the most appropriate expression of the purpose of the building. A pleasing texture and colour of an exterior surface of concrete may be produced by painting red granite aggregate on the facing with special

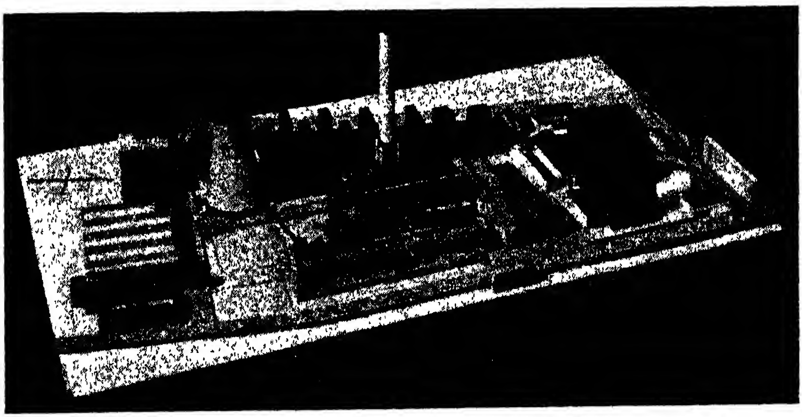


FIG. 45. Power Station Model.

chemicals, although care is required in this direction if good results are to be obtained.

A system of repeatable bays based on the plant unit, with glazing between stanchions, is economic, functional, provides excellent light and is readily extendable. A steel frame lends itself to this rather better than does a concrete one although examples of the latter are to be found.

Some of the existing older stations which are now undergoing modernisation are of substantial brick construction. For example, in two such stations the turbine-house walls are 3 ft. thick and will take a crane capable of lifting a load of approximately 75 tons, *i.e.*, the stator of a 30-MW set. If the existing walls are unsuitable for the loads imposed on them by the crane when fully loaded it will be necessary to erect a crane gantry carried on independent steel stanchions.

In general, it will be found that panelled brickwork relieved with stone courses and having adequate glazing to provide good natural lighting is the type most frequently adopted. Considerable use has also been made of hollow walling, especially for plinths and piers, and in this way a massive appearance has been achieved without undue expense.

The idea of massiveness and power has been incorporated into the building walls by the use of simple lines indicative of height and power. Such treatment is considered a good investment in view of the public goodwill created.

Reinforced concrete has been used and is quite satisfactory both as a structure and from the point of view of cost but care is needed if decorative features are to be included. Reinforced concrete has been used for turbine and boiler-house buildings and in one station the ferro-concrete structure is mounted on piles and forms a monolithic support for each building and each turbo-alternator. In the boiler house this structure extends upwards to the firing floor level 21 ft. above the basement, the superstructure being of steel, enclosed by brick panels with terra-cotta facings.

Reinforced concrete construction with brick cladding is also suitable.

Care is needed in the early stages of superstructure design if reinforced concrete is used in place of steel structures. Providing the work is properly planned and designed, such a construction should be as rapid as structural steel. The main concrete superstructure, including the crane rails, should be completed before the turbo-alternator foundation blocks are commenced just as in a structural steel turbine house. Precast reinforced concrete has also been used for the main members of buildings, and it is claimed to have considerable structural and financial advantages. The weight of reinforcement steel is only about one-third that of the steelwork normally required and, being precast, a saving is made in shuttering and formwork. More accurate and higher-grade concrete and improved finish are obtained compared with cast *in situ* methods. Each member is erected and trued into position and the *in-situ* concrete floors are poured, running in at all points and connections, picking up reinforcing bars left protruding from the members. This makes the beams, columns and floors into a monolithic structure.

Protected metal sheeting is still employed for certain sections of the buildings, such as conveyor galleries and some portions of the boiler house.

Patent glazing with wire-woven glass has the advantages of being

a very light construction, cheaper, quicker in erection, and provides excellent natural lighting. A steel-frame building covered with an insulated metal " sandwich " consisting of galvanised corrugated steel sheets attached to the girts, a centre layer of $\frac{3}{8}$ in. gypsum board coated with heat-reflecting aluminium foil, and a weather-resisting outer facing of asbestos and asphalt-protected metal makes quite an economical covering. The corrugations (1$\frac{3}{8}$ in deep and 5 in. wide) give architectural character and are able to give effect to the size of building. Asbestos and asphalt-protected sheets faced on the exposed underside with an aluminium finish and topped with a layer of fibreboard insulation carrying a built-up asphalt covering, makes a suitable roof. Many of the American stations are substantially constructed with outer walls of brick and stone and the majority are handsome buildings having ornate facias. The amount of structural steelwork used depends upon the types of buildings adopted ; the following are representative of three stations :—

190 MW station (designed to L.C.C. regulations) . .	21,000 tons	
60 ,, station	7,000 ,,	
200 ,, station { turbine house	2,100	(4–50 MW sets)
stoker-fired boiler house	1,600	(8 boilers)
pulverised fuel boiler house	1,800	(8 boilers)
Total	5,500 tons	

Data relating to four recent stations are given :

Installed Capacity (MW)	Civil Engineering Steel (Tons)	Structural Steel (Tons)
100	3,500	4,500
150	8,900	6,700
250	8,000	6,300
*120	1,000	2,200

* Cooling tower station.

A comparison of the various types of construction is given in Table 6.

Much thought has been given to the possibility of attack by enemy aircraft, and in this respect precautions should be taken to deal with blast and splinters from bombs bursting in the vicinity. A solid brick or reinforced concrete wall of suitable thickness is the most satisfactory form of construction, and sub-division of buildings

TABLE 6. *Materials and Relative Costs*

Type of Construction	Relative Cost (Approx.)
Brick	1·0
Brick with steel framework	0·8–1·2
Steel framework with protected metal sheeting	0·8
Steel framework covered with patent glazing and wire-woven glass	0·7–0·8
Reinforced concrete	0·78–0·8

minimises dislocation of plant. The windows should be small and placed high in the walls.

Where the power station is in a seismic area steel-framed structures are satisfactory, but it is deemed desirable to allow for horizontal loads likely to be caused by earth tremors.

A flat roof has many advantages over the pitched roof for it is easy to construct in fireproof materials, gutters are unnecessary, and it affords good access for cleaning, etc.

Buildings should be efficiently ventilated and provision made to prevent condensation, drift rain and snow from the roofs falling on the generating plant and switchgear. The roofs, guttering and downpipes should be designed to handle rainfall at a reasonable rate. Guttering round external faces may be provided with handrails to serve as a walkway to facilitate cleaning. The following should always be kept in mind :—

(1) Buildings should not be damaged or adversely affected by climatic conditions, flood or fire.

(2) Maintenance (repairs, painting, cleaning, etc.) should be a minimum.

(3) Extensions should be possible without affecting the existing plant.

(4) Buildings should be of adequate proportions bearing in mind the cost of land, foundations and structures.

Turbine House. The turbine house accommodates the turbo-alternators and associated condensing and auxiliary plant together with cranes and lifts. It should be constructed to provide for a future generating unit until the ultimate capacity is reached.

There are two principal layouts although variations are to be found. The machines may be arranged at right angles to the longitudinal axis of the turbine house or parallel thereto. The former is perhaps better suited to the short type of machine than the long multi-cylinder machine, unless these are of the cross-tandem types on two separate shafts placed side by side. There is a trend

towards turbines comprising high and low pressure machines on separate shafts. The of the depth basement is reduced if the cylinder cross-over pipes are taken overhead. The condensing plant is fixed in relation to the cooling water system and wherever possible full advantage should be taken to save pumping power.

One popular layout is to divide the width into two parts, a main span for the turbo-alternators and a secondary span for the boiler feed pumps, heaters and evaporators. At least one overhead crane

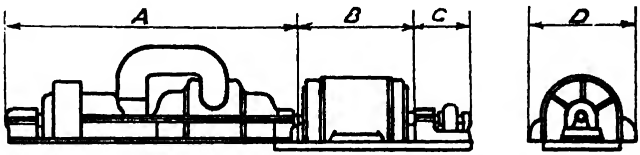


FIG. 46. Overall Dimensions of 3,000 r.p.m. Turbo-Alternators.

Output MW	Steam Conditions		Alternator kV	A Ft. Turbine	B Ft. Alternator	C Ft. Exciter	Overall Length A+B+C	Width D Ft.
	Press lb./in.²	Temp. °F.						
15	350	650	11	20·0	13·25	6 0	39·25	11·75
	600	825	,,	29·75	,,	,,	49·0	,,
30	,,	,,	,,	33·5	16·5	8·0	58 0	13·0
	,,	,,	33	,,	20·5	,,	62·0	,,
50	,,	,,	11	46·25	19·25	7·5	73·0	,,
	,,	,,	33	,,	26·0	,,	79·75	,,

is necessary to handle the plant during construction and maintenance. In some stations a small crane has been provided above the larger crane and is very useful during the first stages of construction and also when maintenance and construction are being carried out simultaneously. The largest and heaviest single item of plant to be handled is the alternator stator, and the following particulars are essential for erection purposes :—

(1) Details of crane hooks.

(2) Maximum height available to the inside of the crane hook above the turbine operating floor.

(3) Limits of cross traverse of the crane hooks measured from the turbine house walls.

(4) Height and location of any plant on the turbine operating floor along the path to be taken by any stator.

(5) Removal space required for withdrawal of electrical rotor and condenser tubes.

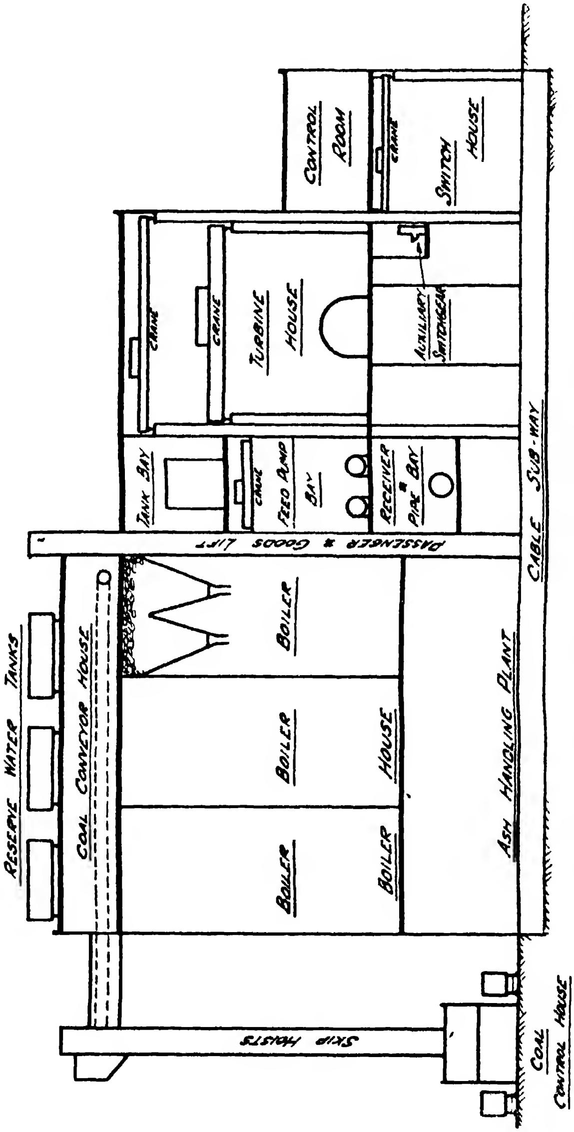
Fig. 46 gives overall dimensions of typical sets. Particulars of cranes are given in Table 7.

TABLE 7. *Turbine House Cranes*

Station	Largest Set (MW)	Turbine House		Feed Pump Bay	Remarks
		Large Crane (Tons)	Small Crane (Tons)	Crane (Tons)	
Dunston	50	120	25	12	Small crane above large crane.
Barking	75	175	30	12	do.
Battersea	105	150	25	15	Small crane on same rails.
Fulham	60	125	—	—	—
Derby	30	75	—	—	—
Blackburn Meadows (Sheffield).	50	100	—	10	—
Swansea	30	150	—	15	—
Bradford	30	100	30	—	—

The architectural details in some cases have been given considerable thought and indeed some very fine features have been incorporated in a number of modern stations, but the decoration should be entirely simple and justify its adoption. In a number of old stations white glazed bricks (up to crane level), were frequently used, and gave a very pleasing appearance. An advantage in this case is that painting is not required, only a periodical wash-down being necessary. Various colours of tiles and salt-glazed bricks for interiors are to be found in practice. The noise in the turbine house may be reduced by including rubber dados on the walls and an acoustic ceiling to the underside of the auxiliary bay floor. Ample natural lighting may be obtained by including large vertical windows in the gables and side walls or by roof lighting. The opening and closing of the windows can be arranged for mechanical and electrical remote control. In some cases, the side walls and also the gables are constructed of almost all patent glazing (with wire-woven glass), except for a plinth wall of brickwork to a height of 15 ft. to 20 ft. This construction provides ample natural lighting, but problems of ventilation and cooling have to be faced. Further, the question of protection against blast and splinters from bombs bursting nearby must not be lost sight of. A very hot sun beating on such

vast expanses of glass causes a large rise in temperature, and means of ensuring a correct working temperature are necessary.



Figs. 47–53. Typical Sectional Arrangements of Power Stations.

Walls and roof may be constructed to embody natural and mechanical ventilators of the louvred and extractor-fan types. A cross-draught system of mechanical ventilation by which air entering

by way of large louvres in the turbine house wall is drawn across the building is also used. Various methods of roof construction are in

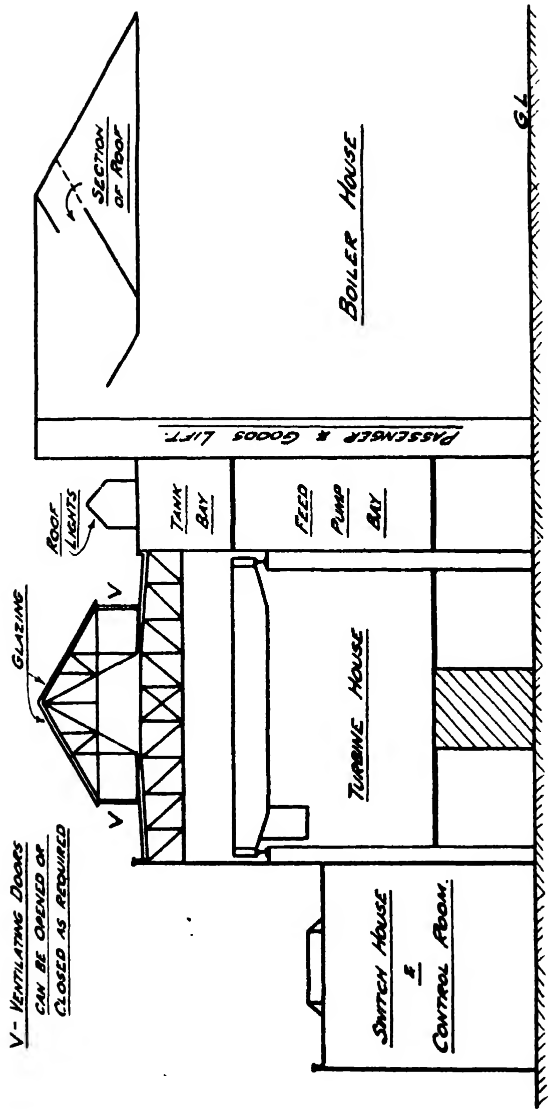


Fig. 48.

use, but the flat roof and apex roof or a combination of both are the ones commonly adopted. The apex-type calls for a light structural arrangement typical of workshops, a large proportion being glazed

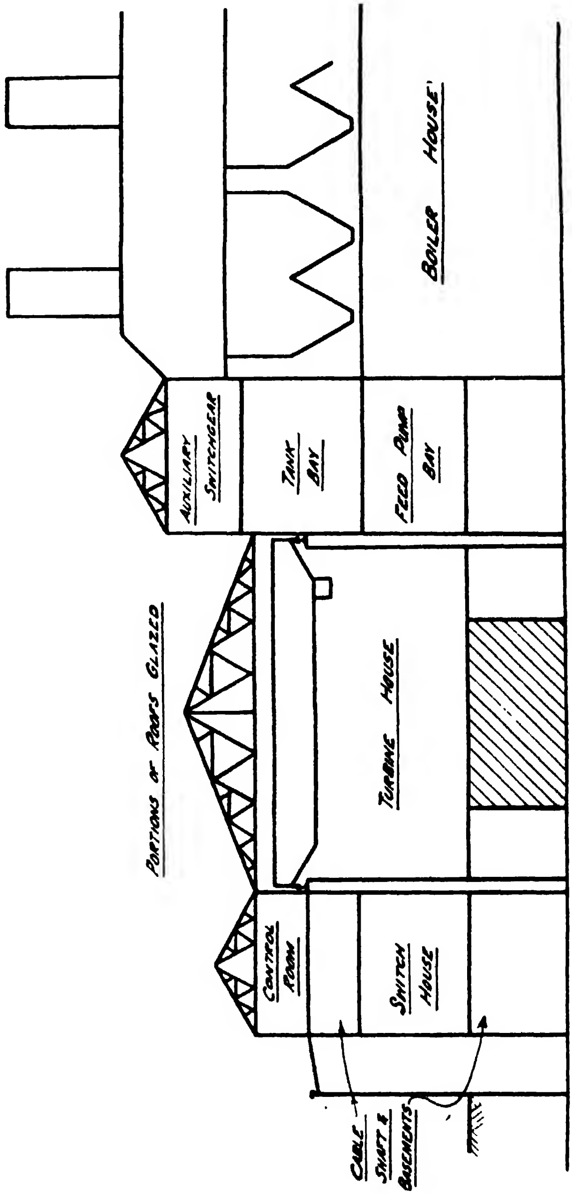


FIG. 49.

to provide natural lighting, the remaining portions being either slated or covered with protected metal sheeting. The flat roof is of reinforced concrete with a layer of asphalt, and roof lights may be

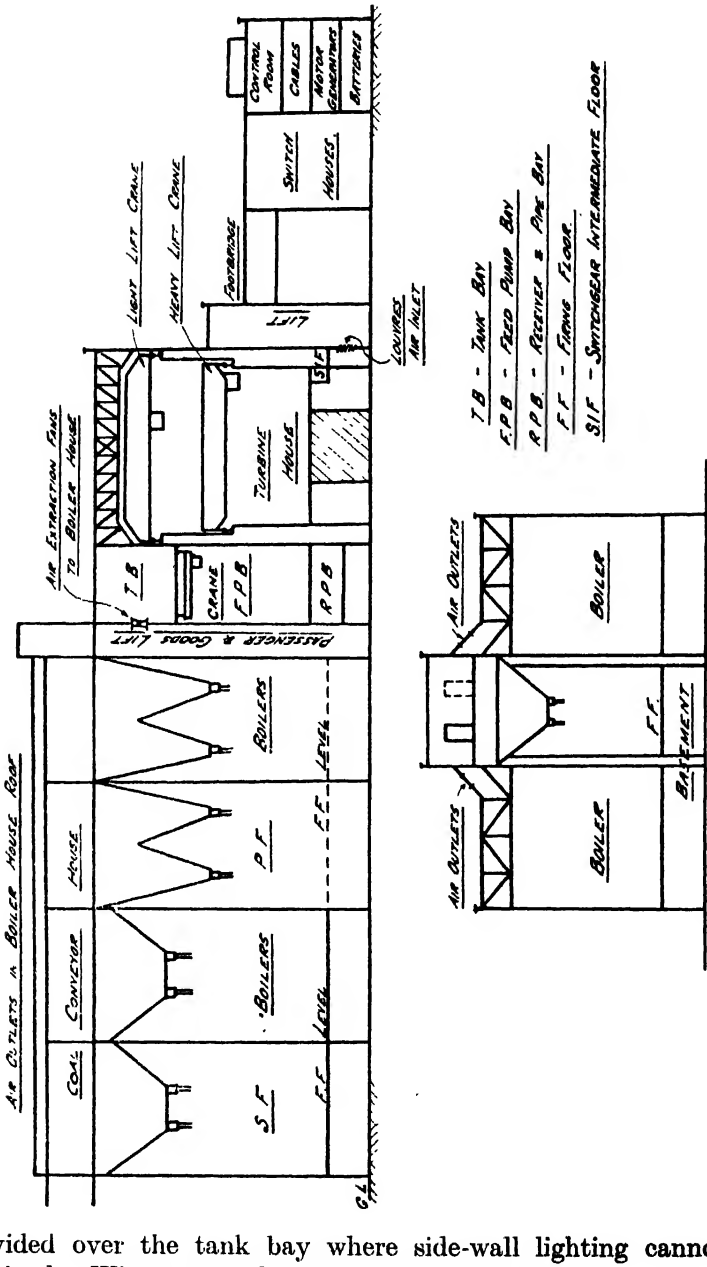


Fig. 50.

provided over the tank bay where side-wall lighting cannot be obtained. Wire-woven glass should always be used.

Roof lights invariably give trouble after installation and in

the early stages may hold up construction, so they are not popular. Condensation on the underside of roofs has to be guarded against, and special forms of roof with insulating properties have been used. Roofs of ferro-concrete supported on steel trusses and covered with a layer of heat-insulating material and waterproofed by asphalt are quite common.

The patent construction consisting of hollow steel beams 18 in. wide and equal in length to the span between roof beams is also in use. The beams are erected with the precast concrete covered side downwards. An area of roof is covered with prepared beams

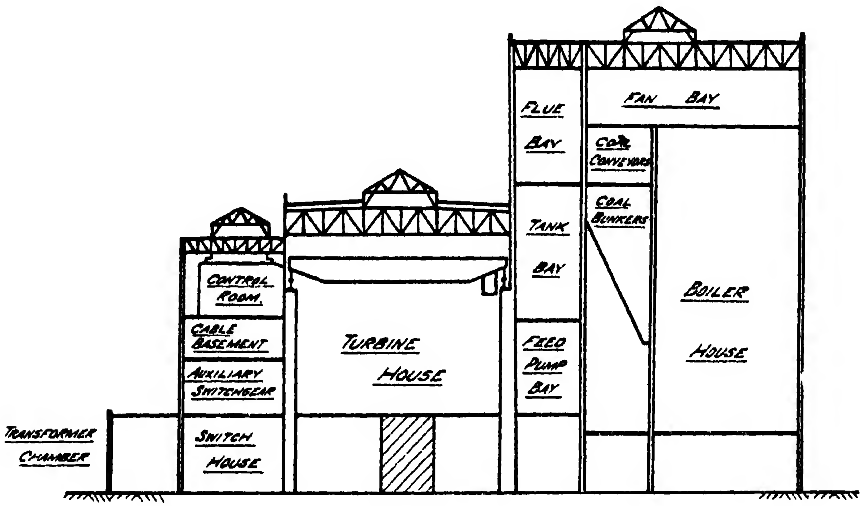


FIG. 51.

after which high-tensile steel fabric is spread over the area, concrete then being poured to a thickness of 1 in. above the crown of the steel beam. The roof is finished off with $\frac{7}{16}$ in. insulating board and patent seven-ply felt in bitumen and, to provide a wearing surface for walking, gravel is spread over the roof whilst the bitumen is still soft and rolled in. Condensation troubles have not been experienced and this type of roof facilitates rapid construction as shuttering is unnecessary and much handling time is saved. One in. thick insulating board has also been laid between the concrete surface and the asphalt to prevent condensation.

Trouble has been experienced due to the movement of the asphalt in hot weather causing splitting and consequent leakage. To reduce noise in the turbine house $\frac{1}{2}$-in. thick sound insulating

material has been applied to the underside of the concrete roof. The main operating floor is generally supported partly on the building columns or walls and partly on the turbo-alternator foundations. Where turbo-alternators having different running speeds are housed in the same building, it has been considered necessary to keep the operating floor entirely separate from the foundation blocks to prevent any possibility of vibration being set up. The floor is supported partly on the building columns and partly on stanchions near

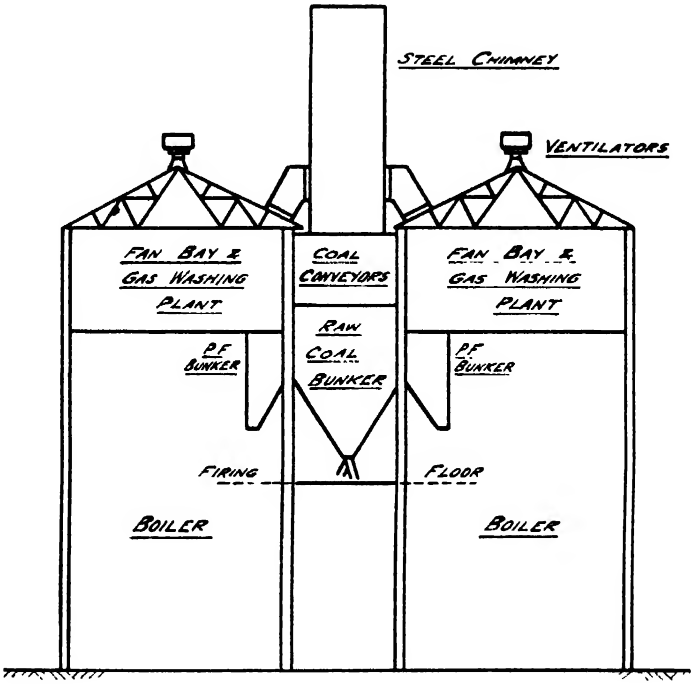


FIG. 52.

the machine foundations. The operating floor should be arranged to give reasonable access around the turbo-alternators with a well-opening adjacent to each set to give natural lighting to the basement and allow operators a clear view of the condensing plant. The foundation blocks cannot be made to line up exactly with the turbo-alternator and it is usual to cut the surrounding floor plates to suit. The construction of the floor is of flat or arch-slabs, about 6 in. thick with 2 in. for tile finish. The tiles used on this floor should not be less than 12 in. square and about 2 in. thick for it is found that small light tiles will not stay put. This is probably due

to the combined effects of repeated expansion, contraction and vibration. Ten-inch and 12-in. square precast terrazzo tiles have proved satisfactory and make a pleasing feature.

The following mixture makes quite a good finish, usually about 2 in. thick, providing a rubbing stone is applied just after initial setting :—

Felspar chippings . .	30
Cement . . .	10
Red oxide . . .	1

(Lamp black is used if a grey finish is desired.)

This mixture is also suitable for finishing off plinths.

The feed pump bay usually follows that adopted for the main bay, although open steel grid flooring has been used to aid lighting of the basement. The flooring immediately around the turbo-set may be of alternatively mild steel chequer-plates or open-grid type. If an electrical annexe or intermediate floor for the auxiliary switchgear is provided the flat-slab construction is preferable owing to the large number of cable holes and slots to be provided, for it is a difficult job to cut holes in curved corrugated sheets. The tank-bay floor should be of concrete since with open-type flooring condensation takes place on the underside of the tanks and becomes a nuisance. A 6-in. floor with 2-in. granolithic finish is suitable. The basement floor slab is carried

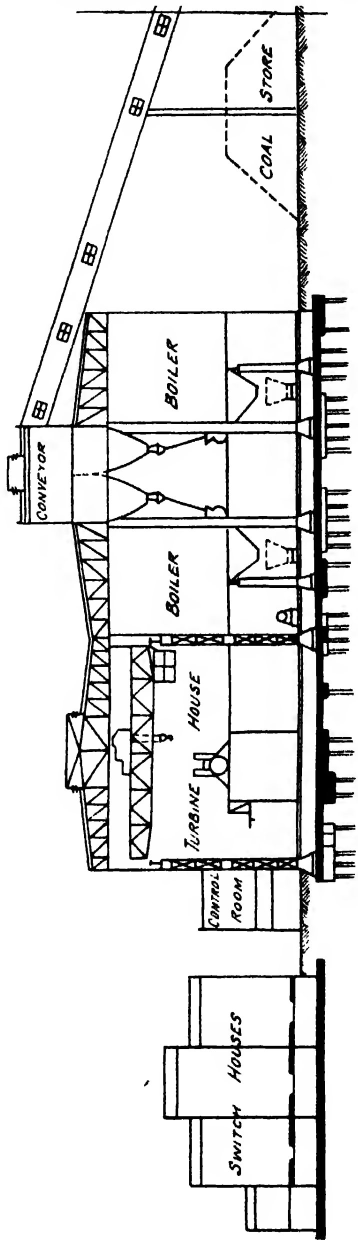


Fig. 53.

on the building and machine foundations, the thickness varying

throughout the basement to suit requirements. The floor may be finished with 2-in. granolithic tiles or special serrated hard bricks. Here again the tiles should be at least 9 in. square, but preferably 12 in. Provision should be made in this floor for pipe trenches, gullies and cable pipes, the latter being put in much in excess of the original requirements.

The floor should fall from the outside walls to a drainage channel

Fig. 54. General View of Battersea Turbine House. Two 64,000 kW., 1,500 r.p.m. three-cylinder turbo-alternators with 5,000 kW. house service alternators. (British Thomson-Houston Co. Ltd. and Metropolitan Vickers Ltd.)

and run the entire length of the turbine house on the centre line of the turbo-alternators. This channel is required to carry away the water from the condensers when they are water tested and opened for tube cleaning. Where this is not convenient the channel may be arranged to serve a pair of turbo-alternators and then be led direct to a circulating water culvert. All pipe trenches and drainage channels may be covered with mild-steel chequer plates. The turbine house should have at least one loading bay, but preferably one at each end. A standard-gauge railway track, and if possible a roadway, should be

taken into each bay. An electrically operated roller shutter of adequate size should be provided. A rail siding can be arranged to run the entire length of the turbine house and then direct into the workshop. A working platform at operating floor level can be placed over the siding opening when overhauls have to be carried out.

The loading bay floor may be granolithic or finished with creosoted wood blocks. It also serves as an ideal place for turning over the turbine cylinder covers for maintenance and repair. A special

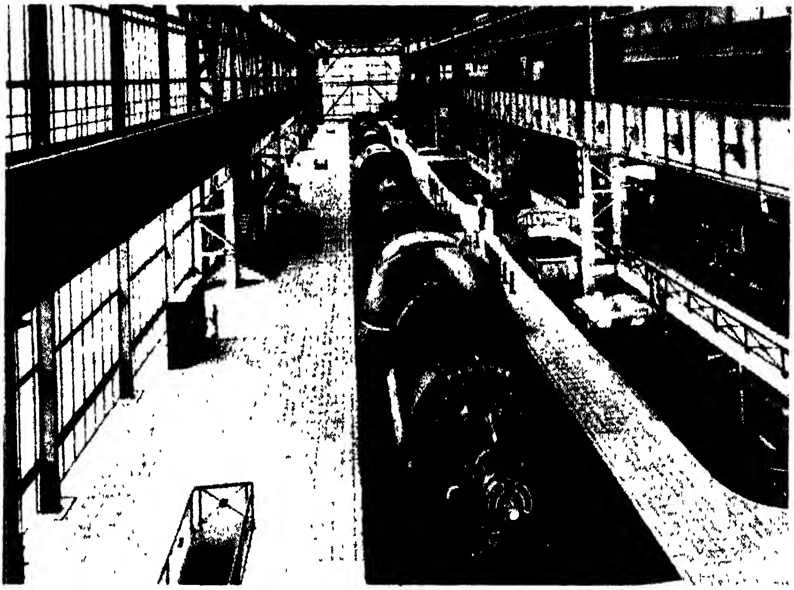


FIG. 55. General View of Dunston "B" Turbine House. Four 50,000 kW., 1,500 r.p.m. turbo-alternators. (C. A. Parsons & Co. Ltd.)

lifting beam is sometimes provided over the bay to facilitate maintenance on the overhead cranes.

The design of the handrailing around the light wells and that used on stairways should be chosen with care, for although this is only a very small point it can materially assist in giving a pleasing appearance. A good layout can be spoilt by unsightly handrailing, and a design which is substantial, neat and without frills is all that is required. The slope of stairways is deserving of care, and usually an angle of 40° to the horizontal is suitable.

Ample provision should always be made for the inclusion of pipes, trenches and basements to cater for the large number of cables.

The means of access for window cleaning should be taken into consideration and may involve some special provision.

In some stations of about 100 MW capacity the turbine house roofs have been constructed in removable sections which can be lifted off by a long-travel Goliath crane. This crane is also used for the handling of the plant and considerable saving is effected in the building construction.

Boiler House. This consists of a number of sections superimposed above each other. First there is the ash basement at ground level which, in addition to accommodating the ash hoppers and ash and flue dust handling plants, may in some cases house the mechanical draught plant and steam receivers. Immediately above the basement is the firing floor at which level the combustion chamber and the boilers are carried. If pulverized fuel boilers are installed then precipitators will be required and can be placed between boilers, or alternatively, at the rear of each boiler. The chimneys and mechanical draught plants can be placed on the firing floor or on a separate floor above the boilers. As with the turbine house space should be allocated for the reception of additional plant in the early construction period by including an extension to the shell of the building. The material and architectural features follow as far as possible those of the turbine house. The boiler house is arranged to house the steam-generating units and associated auxiliary plant together with the coal bunkers for storing a limited amount of coal in case of breakdown or stoppage of the coal-handling plant. The inclusion of coal-storing bunkers materially affects the design of the boiler house, but the steam-generating units may be so arranged that the bunkers serve two rows and keep the ground area required to a minimum. The boiler chimneys sometimes form part of the structure and this in turn may affect the building features.

A point of importance is the fluctuation in temperature which causes considerable variation in the length of the boiler house. In a steel frame building, expansion joints should be provided between the boiler house and turbine house at roof and tank bay floor levels to prevent thrusts of unknown magnitude being transmitted to the turbine-house steelwork.

Ample natural lighting is desirable, and this may be obtained by side wall and roof windows. An improvement is effected by providing good reflecting surfaces by the use of light paints—for example—the bunkers, boiler casings and auxiliaries may be treated with aluminium paint.

Ventilation is very important, and much depends on the position

of the draught plant. Adjustable louvred openings may be provided in the basement walls together with large areas of open-grid steel flooring round the boilers at firing floor level. Where the forced draught plant is placed in the basement adequate provision of air inlets at firing floor level is essential since most of the fresh air will be drawn direct to the fans. Windows should not be fitted with ventilators or shutters too high above firing floor level, otherwise there will be stagnation of hot air behind the boilers. The fans sometimes draw air from the top of the boiler house, which is generally the hottest part of the building, frequently reaching 140° F. to 150° F. In this way about one-half of the heat which would otherwise be lost by radiation from the boiler is returned to the unit, giving an increase in the overall efficiency of approaching 1 per cent. Various forms of roof construction are used, each incorporating special features for the purpose of assisting natural ventilation. The success of these depends largely on the direction and velocity of the wind and may even produce a down-draught of heated air in the boiler house. The ingress of rain should be prevented but in so doing the exit of hot air should not be impaired. Normally the basement is reasonably free from dust, but should the ash-handling plant fail, man-handling of the ashes may have to be resorted to, resulting in a dust-laden atmosphere. This is undesirable in any case, but more so where the draught plant and auxiliary switchgear are housed in the basement. To overcome this the ash-hoppers and handling plant in the basement may be separated by building walls and sealing them off from the remainder of the plant. The necessary trenches for the ash plant should be allowed for in the early constructional period.

Some means of removing the ashes from the basement in cases of emergency or breakdown should always be provided. This may be catered for by running a standard-gauge railway track into the basement or alternatively installing ash trucks or bogies which can be man-handled alongside the ash-hoppers.

If a standard track is to be made use of it is advisable to put it into position at an early date as this will facilitate the erection of the boiler plant.

In stoker-fired installations the firing floor may be tiled or bricked or a combination of both. Two-inch blue brick laid in sand and jointed in cement has been used and tiles should be from 9 in. to 12 in. square. Firing and basement floors of 2-in. granolithic have also been adopted. To prevent dust formation, concrete floors may be brushed to remove all loose particles, the surface then being treated with a mixture of boiled linseed oil and petrol and the process

repeated until a good glossy surface is obtained. An alternative is the periodical application of a silicate solution. Pulverised-fuel installations require only a very small area of solid flooring and in most cases open-grid steel flooring serves all purposes.

The coal conveyors are arranged to run above the coal bunkers, and to prevent the spread of coal dust to the remainder of the boiler house the conveyors are housed in a separate gallery.

The bunkers may be completely covered, except for slots through which the conveyor trippers discharge, or left open and surrounded by handrails. The slots may be covered with a rubber sealing belt which is carried up and round the distributor spouts and affords a seal at any position of the distributor. During coaling operations air may be constantly exhausted from the bunkers and discharged through a cyclone separator to ensure there is no outward escape of dust-laden air through apertures. The construction of the gallery will follow the lines of the boiler house and ample natural lighting and ventilation can be provided by the inclusion of windows or vents of the fixed and opening types.

Storage bunkers are stand-by to coal conveyors and in some cases other handling plant, but the conveyors are so reliable that one station has no bunker whilst another has compromised and provided bunkers which only cover three hours' full-load supply compared with the more usual twenty-four hours.

The bunkers are a principal factor in boiler house design for they are costly, require a great deal of steel and heavy foundations and deprive the firing (operating) floor of natural lighting. The bunkers are usually of the hopper type and may be of steel plate or reinforced concrete construction, the former being the most popular since it is lighter and generally cheaper. A further disadvantage is that trouble is experienced due to perishing of the concrete at the bunker outlets, probably caused by wet coal being held for fairly long periods. If reinforced concrete is used it is desirable to fit easily renewable cast-iron mouthpieces. As a protection to such bunkers 10 in. by 5 in. " paver " blue bricks have been used as a liner. Some methods used are given in Table 8, which apply to raw coal bunkers. Parabolic bunkers have been used and for a given space will give greater storage capacity than hopper types, but are expensive and " hanging-up " is more likely. A patent bunker employs the catenary principle of construction, the load being carried by a series of steel bands suspended from both ends but not exposed to the coal. Cast-iron plates of handable size form the sides and bottom of the bunker and withstand sulphur attacks. A

TABLE 8. *Coal Bunker Data*

Station	Type of Bunker (Slope to Horizontal)	Lining	Capacity (Tons)	No. of Boilers Served and M.C.R. Output
Dunston "B" (SF).	Steelplate 53°.	4½-in. brick work in cement mortar.	2,000 total, 4 bunkers, each 44 × 34 × 25 ft. deep (test bunker, 150 tons).	8–156,000
Dunston "B" (PF).	Steelplate 70°.	do.	2,400 total, 4 bunkers, each 44 × 34 × 37 ft. deep.	8–156,000
Battersea (SF).	Steelplate 63°.	2-in. concrete applied by cement gun and reinforced.	Each 42 × 25 × 53 ft. deep, 700 tons each, 9 bunkers.	4–312,000
Blackburn Meadows "B" (SF).	Steelplate	3-in. grano concrete with reinforcement.	1,600 total.	6–187,500
Bradford (SF)	Steelplate	2-in. gunite.	1,040 total, 2 bunkers. Each bunker has 3 compartments (160, 200, 160 tons). 32 × 18 ft. Centre serves as mixing compartment.	4–180,000
Neepsend (SF)	Steelplate	3-in. concrete with reinforcement.	1,600 total.	5–187,500
Fulham (SF) .	Steelplate 55°.	3-in. gunite.	3,200 total, 4 bunkers, 44 × 24 × 40 ft. deep.	8–260,000
Derby (PF) .	Steelplate 60°.	Unlined.	1,040 total, 4 bunkers.	4–130,000
Dalmarnock (SF).	Welded Steelplate 65°.	2-in. reinforced concrete.	1,200 total, 6 bunkers.	6–200,000

test bunker is sometimes included to hold the coal used during boiler tests, the capacity of this bunker being small compared to the normal bunkers, varying from about 100 to 200 tons.

The plate-thicknesses of bunkers vary according to the design and construction adopted, but are usually from ⅜ in. to ½ in., being stiffened as found necessary by joist sections. By making allowance for the friction of coal against bunker sides where these are deep and narrow, a reduction of pressure is justifiable due to the arching effect set up.

It would appear that the steel plate construction with some form of lining is the best method. Various types of lining have been tried and care is always required in case dislodgment takes place resulting in choking of the outlet valves and shutting down of a boiler. Concrete lining applied by means of a cement-gun appears to be finding favour and should always have some form of reinforcing agent to guard against shrinkage and temperature stresses.

Rubber has also been tried for bunker linings and is resistant to abrasion and corrosion. The linings are usually moulded and fitted at the works, being applied in such a manner that they will not stretch ; round-headed bolts at intervals hold it in position.

Some bunkers are divided into three compartments, the centre one being used for testing or mixing purposes. Such an arrangement is shown in Fig. 56. Another arrangement is to have two down spouts—one immediately behind the other—from which coal and coke are supplied to the grate in two layers, the coal being on top.

The slope of the bunker sides should be such that free flowing of the coal is obtained and "hanging-up" obviated. Where wet and

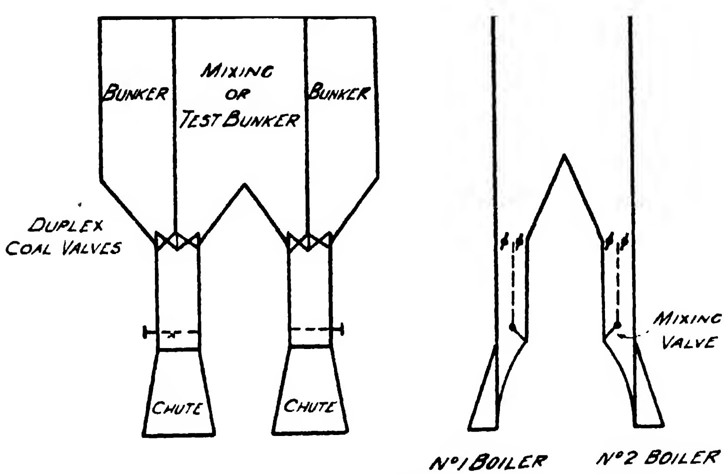


FIG. 56. Bunker Arrangement with Mixing Bunker and Valves.

very poor classes of coal are used such as that consisting chiefly of dust and duff fuel the slope should be as steep as possible, keeping in mind the reduction in storage capacity or increased height of building. For stoker-fired units a maximum slope of 55° to the horizontal will usually serve all classes of coal likely to be handled.

In pulverised fuel installations the raw coal bunkers may have a slope varying from 50° to 70° to the horizontal. Bunkers may be divided transversely by steel plate partitions of suitable thickness. Bunkers divided longitudinally and transversely keep apart different classes of coal and prevent spread of fire. A ladder or climbing irons should be included in each partition to give access from the conveyor galleries to the bottom of each bunker. Hanging chains may be placed in each bunker to enable anyone

accidentally falling in to grasp the chains and prevent themselves being drawn into the bunker bottom.

To facilitate handling of fans, motors and other plant on top of the boiler house and give access thereto for maintenance and general inspection, a combined passenger and goods lift is essential. The lift should be arranged to give access to all floors in boiler house and turbine house. If a small lift suitable only for passengers is pro-

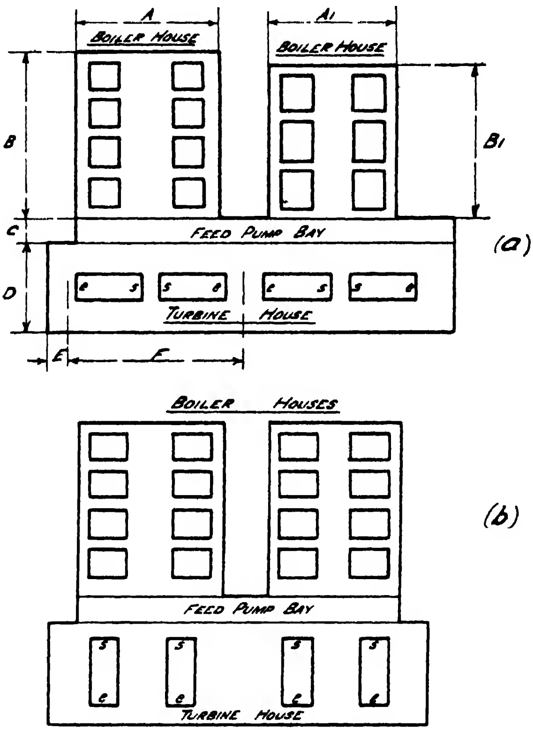


FIG. 57. Typical Station Layouts.

vided it will be necessary to make some provision for handling materials from the boiler-house basement to the firing floor level. Sections of the firing floor may be so constructed that they can be removed to give access to the basement for the purpose of handling materials. A noticeable feature of present-day boiler-house construction is that an overhead crane is not provided even though boiler components involve weights comparable with those of turbo-alternators. A crane would facilitate construction and maintenance work and by careful arrangement of the boiler plant it may be possible to incorporate one. It may, however, be argued that the

larger components of the turbine such as casings and rotors have to be completely removed from the unit whereas the usual maintenance to boiler plant may be done on the units themselves. Lifting blocks are capable of dealing with the components likely to require attention and should be provided to facilitate maintenance. Data relating to turbine and boiler houses are given in Table 9, which should be noted in conjunction with Fig. 57. The layouts usually fall into two classes. In the first the boilers are arranged in rows at right angles (T layout) to the turbine house and in the second they are either in a single or double row running parallel to it. There is no merit in boiler houses at right angles to the turbine house unless they secure advantages. This arrangement offers advantages for very large power stations but is not generally economical for smaller ones. The coal and ash handling plants are separate for each boiler house, which is an advantage during extensions, and the pipework layout may also be improved. The building is more costly since an additional side is required and the intervening space between successive boiler houses is not often put to full use, although electrostatic precipitators may be located here. The effort made to reduce the size of the buildings is helped by the adoption of large capacity units and, whereas the average figure for stations put into service in the immediate post-war years was between 45 and 60 cub. ft. per kW. of installed plant, typical figures for stations recently designed range from 28 to 33 cub. ft. It has been stated that the average value is about 53 cub. ft. per kW., made up as follows :—

Boiler house	33·0
Turbine house	18·0
Other buildings	2·0
	53·0

Typical present-day figures are :

Installed Capacity MW	Building Volume cu. ft./kW
100	40
150	55
250	39
*120	27

* Cooling tower station.

Where electrostatic precipitators are installed it will be necessary to provide houses to take the H.T. transforming and rectification plant. The roofs and walls are usually of reinforced plaster construction whilst hollow beam floors are quite suitable. The latter

TABLE 9. *Floor Area and Cubic Capacity of Boiler and Turbine Houses*

Turbo-Alternator Output MW: M.C.R.	Type and Boiler (lb. per hour M.C.R.)	Steam Pressure (lb. per square inch)	A (Feet)	A_1 (Feet)	B (Feet)	B_1 (Feet)	C (Feet)	D (Feet)	E (Feet)	F (Feet)	H_p (Feet)	H_t (Feet)	H_b (Feet)
12·5 (*b*)	50,000 SF.	275	120	—	140	—	20	70	25	105	63	60	65
32·0	75,000 SF.	300	300	—	160	—	—	50	20	150	—	72	60
50·0	156,000 SF.	625	122	—	198	—	25	70	30	180	91	91	91
50·0	270,000 PF.	400	—	120	—	160	25	65	30	200	90	70	90
50·0 (*b*)	176.000 SF.	450	112	—	175	—	25	110	28	140	92	115	92
75·0	256·000 SF.	625	125	—	225	—	25	75	30	260	94	94	82

Turbo-Alternator Output MW M.C.R.	Turbine House Floor Space (sq. ft. per kW.)	Turbine House Volume (cub. ft. per kW.)	Boiler House Floor Space (sq. ft. per kW.)	Boiler House Volume (cub. ft. per kW.)	Pump Bay Floor Space (sq. ft. per kW.)	Pump Bay Volume (cub. ft. per kW.)	Total Floor Space (sq. ft. per kW.)	Total Volume (cub. ft. per kW.)
12·5 (*b*) 3 sets	0·196	11·75	0·448	29·20	0·064	4·00	0·708	44·95
32·0	0·117	8·50	0·300	18·10	—	—	0·417	26·60
50·0	0·126	11·50	0·242	22·00	0·031	2·78	0·399	36·28
50·0	0·130	9·10	0·192	17·20	0·030	2·70	0·352	29·00
50·0 (*b*) 2 sets	0·154	17·80	0·196	18·00	0·028	2·68	0·378	38·48
75·0	0·130	12·30	0·187	15·40	0·028	1·96	0·345	29·56

are cheaper since shuttering is eliminated and the time required for reconstruction is reduced.

The concrete plinths for the plant are placed as desired on the hollow beam floors.

Chimneys are dealt with in Chapter VII.

Switch House. The switch house accommodates the turbo-alternator and feeder switchgear, which is generally of the high-voltage type, together with associated auxiliary equipment such as batteries, motor generators, oil purifiers, fire-fighting and metering apparatus. The architectural features generally follow those of the main buildings. The form a switch house takes will depend chiefly upon the type of gear to be installed.

The design and construction of switch houses, control room, etc., are dealt with in detail under switchgear in Volume II.

Pump House. This houses the circulating water pumps, bilge pumps, valves, crane and allied switchgear. The building is generally in keeping with the main buildings. The features outlined under the turbine and boiler houses will in most cases apply equally well to the pump house. Good natural lighting and ventilation should be provided. The superstructure may be of the steel framed type erected on the concrete walls of the pump chamber, with brick walls and a flat concrete roof.

Open steel grid flooring may be used at pump floor level and has the advantages of aiding the natural lighting and providing a means of ventilating the pump chamber. The layout will depend upon the type of pumps used and site conditions obtaining. Where riverside coaling is in use it may be necessary to provide a ventilating plant to prevent the ingress of coal dust to the pump house during coal unloading periods. The outside air is passed through a filter to the interior of the pump house, the plant being of such capacity as to keep the air in the house at a slight pressure above the outside air. To facilitate installation and maintenance, an overhead crane or lifting block should be provided. Some form of heating may be necessary to maintain the pump chambers free from dampness.

Workshops and Stores. The workshops provide accommodation for the machinery required in connection with the repair and maintenance of the station plant and comprise a machine shop, blacksmith's shop, electrical shop and joiner's shop. The stores house the materials and spares associated with the maintenance and operation of the plant, and include separate sections for general, oil, paint and lime and soda stores, etc.

Fig. 58 shows one arrangement and Fig. 59 gives an alternative

for the same sections. The latter layout incorporates an overhead crane the full length of the main shops and stores. The issue of stores is controlled from the office counter, and subsidiary apartments are grouped around the main divisions, an orderly elevation being obtained.

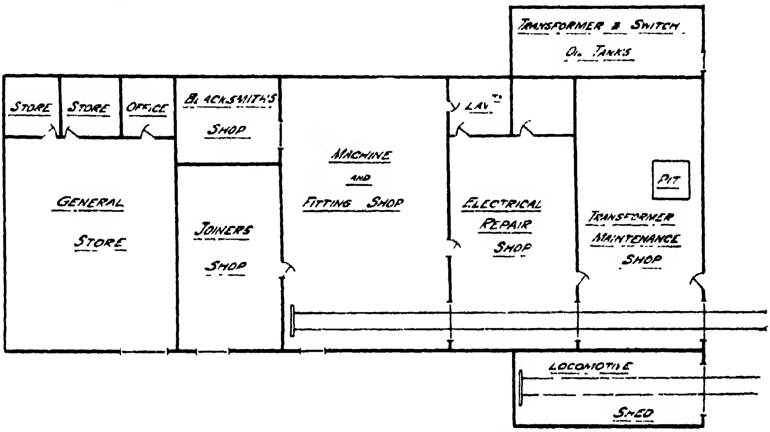


Fig. 58. Layout of Workshops and Stores.

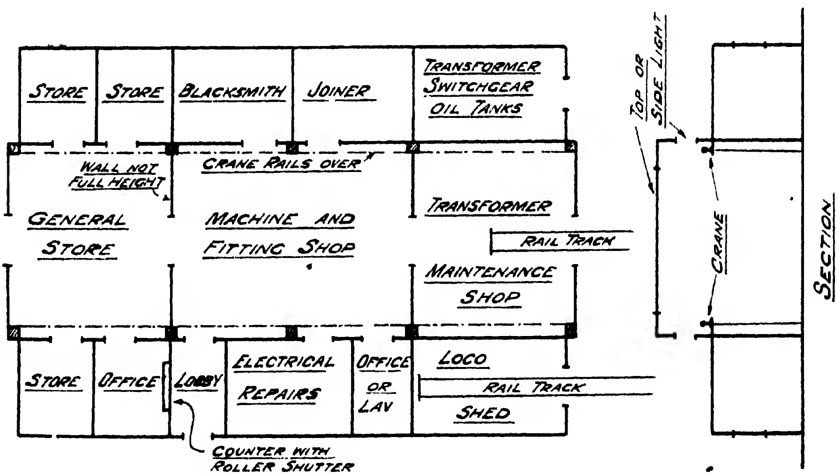


Fig. 59. Alternative Layout.

The buildings are generally in keeping with the main buildings and the layout of the various departments should be placed in correct order. Concrete floors with 1-in. granolithic finish will serve in most cases but in certain parts of the workshop wood sets can be used to advantage. Concrete with a layer of wood on top may also be used.

A mixture of sand and ashes is suitable for the floor of the blacksmith's shop and it can be kept moist by sprinkling with water.

An inspection pit and crane or runway joist and geared pulley block should always be provided. Adequate natural lighting and

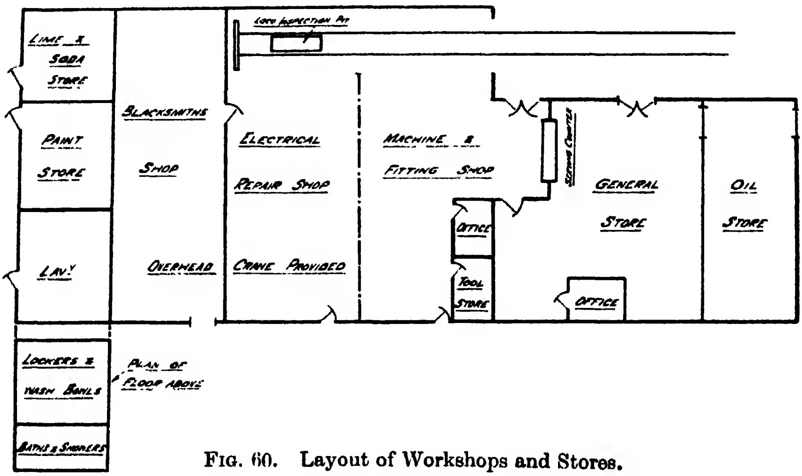


FIG. 60. Layout of Workshops and Stores.

good ventilation are desirable, the temperatures of the various buildings should be maintained at the necessary levels. Fig. 60 shows another layout.

Offices and Messrooms. The administration staff should have adequate office accommodation and the operating and maintenance

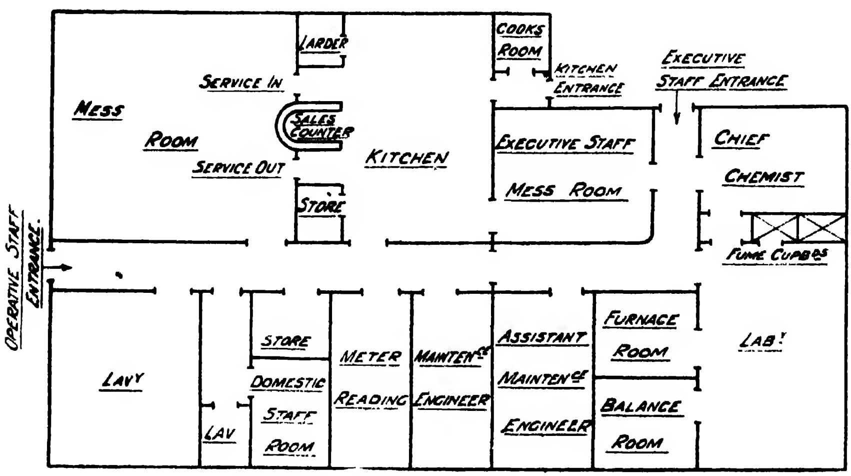


FIG. 61. Staff Accommodation.

staffs should also be provided for. The staffing arrangements vary in every undertaking but the following is typical of a large power station :—

(1) Station Superintendent (or Resident Engineer).
(2) Assistant Superintendent.
(3) Chief Maintenance Engineer.
(4) Assistant Mechanical Maintenance Engineer.
(5) Assistant Electrical Maintenance Engineer.
(6) Chemist and Testing Engineer.
(7) Shift Charge Engineers.
(8) Combustion Engineer.
(9) Chief Clerk and Stores Overseer.

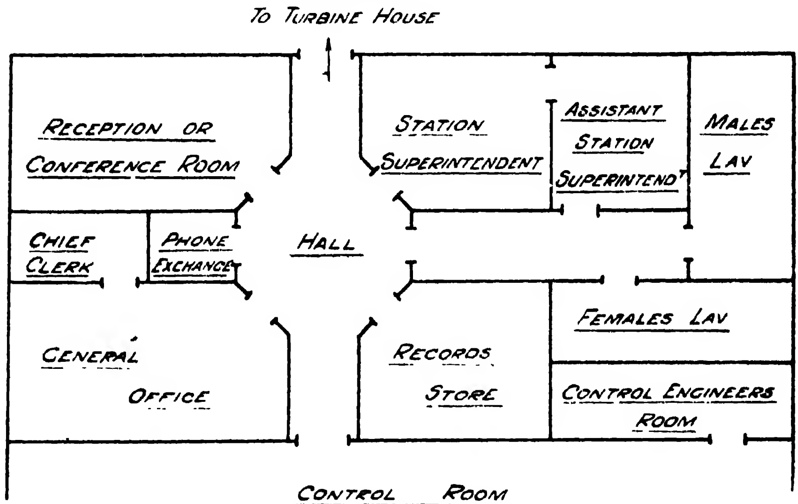


FIG. 62. Staff Accommodation.

Typical layouts showing the positions of the various offices for the staff and their subordinates are given, some of the layouts being the suggestions of J. Cunningham, A.R.I.B.A. In large stations the welfare section is of considerable importance, and the necessary messrooms, kitchen, cloakroom accommodation, lavatories and shower baths with hot and cold water, changing rooms and lockers should be provided. A first-aid room is also necessary, trained personnel being drawn from the station operators and staff.

In this arrangement the executive and operative staff sections are segregated, with separate entrances. The kitchen layout is improved, there being a separate entrance to it with a lobby to the cook's room, which can have wall windows. The laboratory has considerably more window area and has fume cupboards.

The domestic rest room is near the kitchen and its shape is also improved together with added intervening ventilated lobby.

In Fig. 62 the corridors and hall are compact and direct. The room projecting into the control room and the reception room and general office have an improved shape.

The accommodation required for turbine and boiler house staffs is illustrated in Fig. 63 and alternative arrangements are shown in Fig. 64.

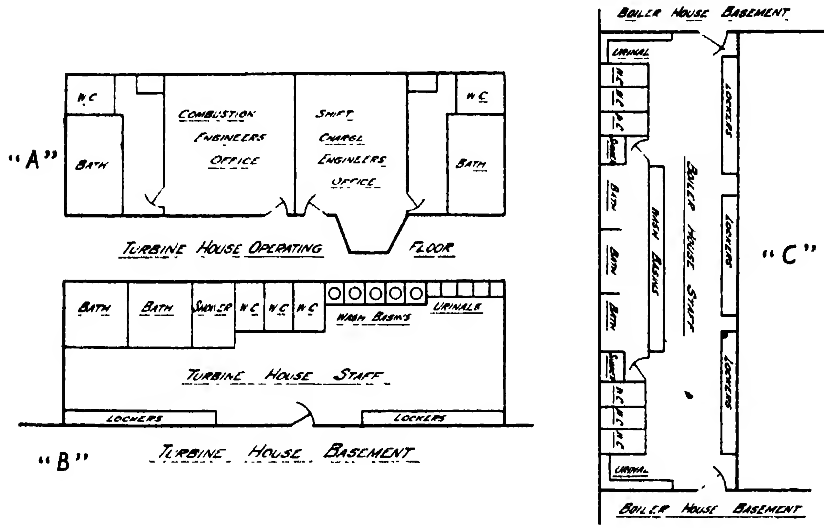


FIG. 63. Accommodation for Turbine and Boiler House Staffs.

In Fig. 64 "A" the bathrooms are regrouped making for simplified plumbing and sanitary arrangements although the offices are farther apart.

"B" layout has been sub-divided as this is better for traffic arrangements and is more hygienic from the bathing viewpoint. It also enables the latter to be shut off when desired and an entrance lobby is included. Circular automatic "wash fountains" can be used instead of basins, and are more economical and hygienic. Similar remarks apply to layout "C." Ample natural lighting, good ventilation, sufficient heating and absence of noise are essential. The construction of the various offices will to some extent depend on the position. Where they adjoin and overlook the turbine house, vibration and noise should be eliminated. The windows overlooking the turbine house may be made of double construction having a

cavity of 2 to 4 in., the panes being set in steel sashes fitted with wash leather to prevent vibration.

A conference room is sometimes provided for committee and staff meetings.

For heating and hot water supplies calorifiers may be installed in the boiler house, being supplied with low-pressure steam reduced from the main steam ranges.

Heating coils may be concealed in the ceilings and floors.

A heat pump installation using Freon gas as the refrigerating medium and low-grade heat from discharge of the circulating water system is also possible and has been installed in a few stations.

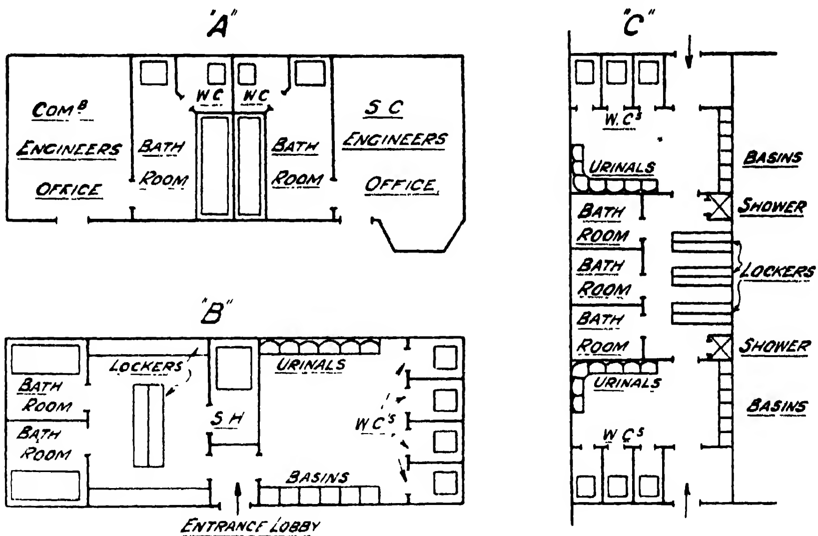


FIG. 64. Alternative Layouts.

Laboratory. The chemical and testing section is a department of growing importance and one that will play a big part in the power stations of the future.

A properly equipped laboratory should be provided at each station and should include balance and furnace rooms, and sample house. Accommodation may also be made for instrument repair and meter calibration.

Garage and Cycle Park. The need for garage and cycle park space has increased to such an extent that this should be allowed for when the layout is being considered.

The space required to house the cycles may be kept to a minimum by using one of the racking arrangements now available.

SITE WORKS

Drainage System. Good design and construction are essential to prevent trouble from pollution of the site, and ingress of polluted air to buildings.

The principal factors to be considered when laying out drainage systems are: (1) they should be laid with self-cleaning gradients, (2) all main junctions and changes of direction should be made in inspection chambers to ensure access for rodding, the drains being laid in approximately straight lines from chamber to chamber; (3) adequate ventilation should be provided; (4) they should be of sound construction to remain water and airtight; (5) all chambers excepting those near the surface should be of adequate size to facilitate rodding.

Two separate systems of drainage may be provided, one for sewage and one for storm water and sump discharge generally.

The systems may be divided into groups depending on the extent of the layout. Portions of the roof water may be taken into the sewage system to assist in flushing the channels. An intercepting trap should be included where the station drainage system enters a main sewer to isolate and seal the latter from the former. A manhole or disconnecting chamber is provided to give access to the intercepting trap for inspection and cleaning. This should be inspected at regular intervals to ensure that there is no accumulation of silt, etc., in the trap which would result in stoppage.

The sewage and storm-water pipes are of varying sizes of good quality glazed stoneware, except in special positions (below cables), when cast iron is used.

Stoneware pipes jointed with tarred yarn and Portland cement and surrounded with 6-in. thick concrete are usual. Main sewage and storm-water pipes may be 9 in. and 12 in. and the subsidiary branches 3 in., 4 in. or 6 in., as required.

A sewage purifying plant may be necessary and allowance should be made for this in the early stages of construction. The functions of a sewage plant may be briefly summarised as follows:—

(1) To receive the sewage of its contributing area, which consists of the entire water supply of that area—after use by the station staff and employees—together with the rainfall, the whole being sent to the plant for purification.

(2) To separate by various means as much of the suspended solids as possible in the form of a sludge.

(3) To purify the remaining liquor, which is the bulk of the sewage.

(4) To dispose of the sludge as hygienically and cheaply as possible.

Sewage sludge is a very complex mixture containing a large amount of water (80 to 96 per cent.).

In stations away from the usual sanitary facilities a complete system of rain water and soil drain is provided, the rain water being carried into collecting pits and the soil drainage to a sewage disposal tank, fitted with filter beds, automatic sewage distributor and pump.

Roadway Drainage. The drainage gullies for roadways may be connected to the storm-water or sewage system where it is convenient to do so. Where this is not permissible separate soak pits are occasionally used.

Water Supply. Water supply for general services may be obtained from a water company's main or wells where these are at hand. A 6-in. or 9-in. pipe will normally deal with all station requirements. When town main water is used for boiler make-up adequate storage capacity should be provided in case of interruption of supply.

Drinking water is taken from the town main although in some cases evaporator water is passed through coolers for this purpose. Where the water is heavily impregnated with salt and unsuitable for drinking purposes this has been adopted.

Railway Sidings. Railway tracks should encircle the entire site to facilitate marshalling of full and empty coal wagons, ash removal, delivery of goods to stores, handling of plant and goods to and from the workshop and loading bays.

Use should be made of the site levels to assist in the movement of wagons, an example of this being the layout and arrangement of the coal-handling plant. The wagon tippers may be located so that the incoming and outgoing lines are at higher and lower levels respectively, in which case movement of the wagons by gravity is possible and considerable economy is effected.

The sidings turn out to the main lines of a railway company, and certain sections will have to comply with its requirements.

The clearances between rails and nearby buildings, lamp standards, etc., are in accordance with the appropriate regulations.

The surface of the site should be properly trimmed before being ballasted, and drainage by earthenware drain pipes laid with open joints in a trench filled with coarse clinker is desirable.

The formation should be well rolled and consolidated before laying the bottom ballast, the bottom and top ballast being of fine clean ashes laid to approved depths. The rails used for the construction of turn outs and crossings are of new sections, but rails in plain trackwork may be of selected secondhand sections. Sleepers, fishplates, chairs, keys, fishbolts, etc., should be in accordance with

the appropriate specifications. Sidings are referred to under coal-handling plant.

Site Fencing. The amount of fencing required and the designs to be adopted will depend chiefly on local conditions, but allowance should be made for this work. A really good site fence around the perimeter of the station is very useful in preventing unauthorised access.

Landscape Gardening. This may appear to be unnecessary for power stations, but there may be some odd corners which can be made quite attractive by the careful choice of shrubs and plants.

OUTDOOR STATIONS

With the object of reducing capital costs, the erection of plant out of doors has been considered, and in some countries actually tried.

Outdoor switchgear is frequently adopted and there are no reasons why the turbine and boiler plant should be housed providing the climate is suitable. Buildings would still be necessary for offices, workshops and stores and to house the control equipment.

In this country it does not appear justifiable to eliminate buildings, and only in few cases has the switchgear been placed outdoors for power station services. Transformers and reactors are the only items of plant which have been placed outdoors. In view of the very high cost of building work attention is now being given to semi-outdoor plants.

In one semi-outdoor American plant an endeavour has been made to maintain the effectiveness of the pneumatic controls, air soot-blower system and miscellaneous water lines under winter conditions by protecting all exposed control and water piping which is subject to freezing by means of resistance wiring. Single conductor, lead-covered heating cable (19 W.G.—220 V.) has been used in units of 120 ft. of dual run, providing 60 ft. wrapping lengths. Thermostats have been provided to hold air and water at regulated temperatures above freezing. Further information will be found in the *Electrical World*, November 5th, 1951.

CHAPTER III

CIRCULATING WATER SYSTEMS

SITE conditions determine the method to be used for supplying the cooling water to the condensers, and may be one of two systems, namely :—

(1) River, sea, or canal water system or possibly a lake system.
(2) Cooling tower system.

or alternatively a combination of these. Rivers and canals are used where ample water is available, but where this is limited the second system or a combination of both will be adopted. It may be necessary to pump the make-up water some miles but the difference in head is only moderate and the pumping charges are therefore reasonable. This resolves itself into a problem of saving in transport of coal compared with pumping charges. The maintenance of the desired vacuum depends not only on the quantity of water sent through the condenser, but also on the temperature of the water.

To illustrate this point a 30 MW set working on both systems with feed heating is given in Table 10. The figures given for vacuum are calculated at 80 per cent. load, *i.e.*, economical rating or a condenser loading of about 24 MW. Local conditions may dictate wide variations.

TABLE 10. *Cooling Water Data*

System	M.C.R. of Set (MW)	Cooling Water (Gallons per Minute)	Cooling Water (° F.)	Vacuum (Bar. 30 in.) (Inches Hg.)	Condenser Cooling Surface (sq. ft.)
River water	30	20,000	55 60	29·0 28·8	25,000
Cooling tower	30	27,500	80	28·0	29,000

The theoretical lower-temperature limit of the thermal cycle is the temperature of the water in the river (this cannot be altered), and for cooling tower systems, it is the atmospheric wet-bulb temperature.

The common law gives every riparian owner the right to have water flowing past his land in its natural state of purity, and it also enables him to free passage of fish up and down the river. The great

difficulty has usually been for an individual owner or tenant to enforce these rights owing to the expense entailed in going to law. In this country the Anglers' Co-operative Association has fought and won numerous cases of river pollution.

The cooling water required for a river scheme is about 50 gallons per hour per kW., and the make-up water necessary for a cooling tower layout about 0·5 to 1·0 gallon per hour per kW. The circulating water conditions have an important effect on generating plant capacity. In a cooling-tower system the water temperature on a hot day in summer may be anything from 30° to 50° F. more than on a cold day in winter, and the consequent loss in vacuum may result in a 10 per cent. difference in steam consumption. This would necessitate 10 per cent. more generating plant to carry the same load on the hot day than on the cold day.

The winter peak load is usually much higher than the summer peak, but if the difference is very small more plant must be available to meet the summer peak than the winter peak.

Use has been made of the warm circulating water for water heating systems, etc.

River Water System. The water is drawn direct from the river, pumped through the condensers, then discharged to the river at a higher temperature, probably 10° to 26° in excess of the inlet temperature.

Situated on the banks of a large river or estuary, a station has the advantage of an inexhaustible supply of circulating water.

The positions of the inlet and outlet works should be chosen to take advantage of the maximum available natural cooling by spacing these two points as far apart as possible. In small rivers and canals it is possible to get re-circulation, that is, the warm water from the outlet entering the inlet, thus impairing the efficiency of the condensing plant. Even on large tidal rivers this may take place at certain periods of the tide if the inlet and outlet works are not sufficiently far away from each other. Where there is any doubt about the effectiveness of the cooling water intake and discharge, *i.e.*, interference due to re-circulation, it is possible to determine operating temperatures by producing a working model. In one case a model 1/150 full size of the river was set up and tidal model experiments were carried out and a satisfactory design evolved. Model tests were used to measure the temperature rise at the inlet to the circulating water system. On small tidal rivers (minimum flow of 5 million gallons per hour) the flow may be augmented by impounding tidal water by constructing a weir across the river. A diversion

wall or midfeather is sometimes made in small rivers to carry the outlet water a considerable distance down-stream and so prevent re-circulation. Some stations are designed with the intake on one side of the river and the outfall on the opposite side. Tunnels are driven under the river and outfalls constructed for cooling water on the opposite side from the intakes. The temperature of the outlet water should be kept within safe limits to prevent harm to fish.

To meet the requirements of the Fisheries Board in one district it was necessary to extend the outlet end of the discharge culvert over a spillway about 100 ft. in length on the river bank. Such an

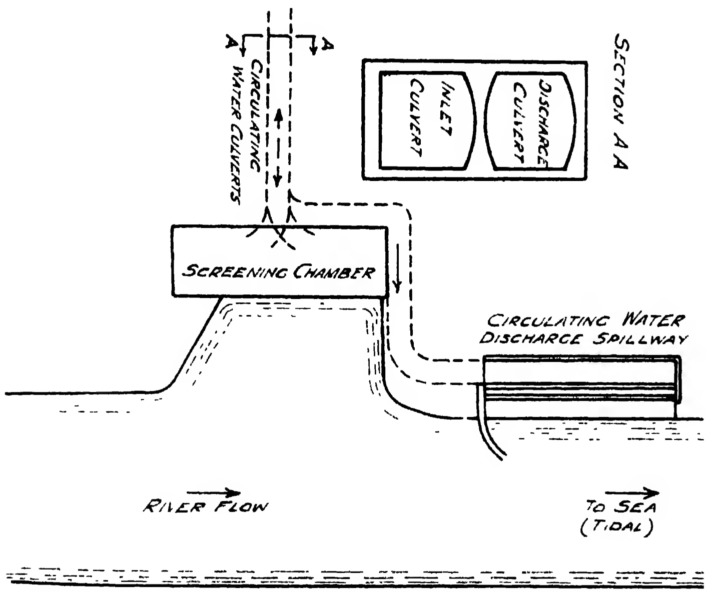


FIG. 65. Layout of Circulating Water System with Spillway.

arrangement is shown in Fig. 65. On one river the outlet temperature of the cooling water was limited to 75° F. for fishing reasons and this necessitated the use of single pass condensers. In another case it was laid down that the river should not be heated to more than 90° F. or to more than 20° F. above the river temperature, whichever is the less.

A system embodying a river and cooling towers to overcome re-circulation and meet the requirements of a fishery board on a fairly small river is of interest. Trouble was experienced due to re-circulation and complaints were made by the river board regarding harm to fishing by exceptionally warm water. The water from

the condensers is discharged into the river at a point near the station, and after mixing with the river water an amount is drawn from the river at a point down-stream and pumped to the cooling towers, where it is further cooled. In this way the water discharged to the river is maintained at a suitable temperature and re-circulation troubles are eliminated. The disadvantage of such a scheme is the necessity for two pumping plants with consequent increase in pumping charges. One set draws water from the river and discharges to the towers and the other takes it from the tower outlet culvert and delivers it to the condensers. Fig. 66 shows a typical layout. A third pumping set may be installed to draw water direct

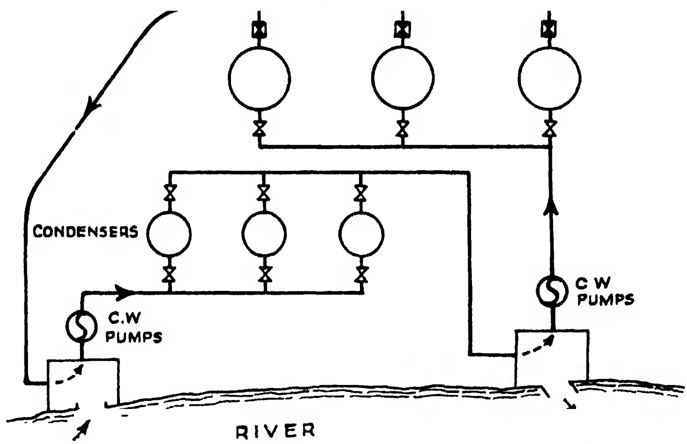


FIG. 66. Combined River and Cooling Tower System.

from the river for delivery to the condensers. The culvert is also an additional item and it is sometimes necessary to provide a jib crane for grabbing the silt from the culvert. Some of the advantages of this scheme are :—

(1) Where the site area is limited the size of cooling towers can be reduced.
(2) A smaller quantity of cooling water is required.
(3) The turbine plant efficiency is increased.
(4) The towers being some considerable distance from the station, a saving in discharge pipework and pump power is possible.

The cost of additional pumping plant will partly off-set these savings.

Another installation of interest is that where the cooling tower (2,500,000 gallons per hour) is a considerable height above the power station site. The river water passes through two culverts with rotary screens into storage reservoirs at the same level, whence it is pumped through the condensers and then returns to other reservoirs at the same level. From these it is delivered into the cooling tower and returns to the intake reservoirs, passing through water turbines on its way. These turbines are coupled to the motors driving the main pumps and a certain amount of energy is recovered. The cooling tower has two ponds, the levels of the upper and lower being 107 ft. and 47 ft. above the storage reservoirs. Use is made of these heads to economise in power required for pumping by returning the water from the tower to the reservoirs through water turbines coupled to the pumping units. The estimated saving in pumping horse-power at full load is 630 h.p. and 280 h.p. for the high and low ponds respectively. The pumps are installed immediately above the reservoirs.

The amount of cooling water required for condensing purposes in a 300 MW station would be approximately 12,000,000 gallons per hour, and allowing for auxiliary service and make-up water a total of some 15,000,000 gallons per hour would have to be drawn from the river. Unless records are available, some preliminary work will be necessitated to estimate the flow of river water at all seasons of the year. The average velocity may be ascertained by taking flows at a number of points by means of floats and the contour of the river bed may be taken by the usual sinker method. From these data the approximate flow can be calculated. Where more accurate results are desired, measuring weirs may be used, due allowance being made to cover all conditions in tidal rivers.

On small rivers where the water flow during certain seasons is low it is sometimes necessary to include a low-water dividing wall down the centre of the river to divert the flow to the screens during times of low water.

The circulating water pumps should be placed so that they are drowned at all recorded river levels, to avoid the use of foot valves and special priming arrangements. This arrangement entails more civil engineering work, and on small stations up to 100 MW output may not be justifiable. In such installations the adoption of horizontal pumps with foot valves is usual. Where the river frontage is limited, the inclusion of a dry pump pit for vertical pumps may not be possible, due to reduction of water chamber space.

The condensing plant should be placed at such a level as to

require the minimum amount of pumping consistent with reasonable costs of basement excavations and foundations. The circulating water system should be designed to utilise the full effect of siphonic action, the pumps being flooded and the outlet from the system being sealed at all river levels. To place the condensers too high may bring the top of the siphon to the critical barometric point, while, on the other hand, the lower they are placed the greater will be the cost of forming the condenser basement.

A level has therefore to be chosen at which the annual savings in pumping, due to siphonic effect, exceeds the capital charges on the civil engineering work. At this point it may be anticipated that a siphonic effect approaching 50 to 70 per cent. of the theoretically possible would be obtained. Tests may be taken to verify the estimated figure.

At various points throughout the system air cocks should be provided to release any air which may prevent the functioning of the siphonic action upon starting up the pumps. If siphonic flow of the circulating water can be obtained at all states of the river level, large reductions in pumping power are brought about.

In very large circulating water systems it may be justifiable to provide air exhauster pumps at various points to ensure siphonic flow at all river levels.

In one station a reciprocating air pump was connected to the condenser discharge branch, the water outlets from the air cooler, oil cooler and transformer oil cooler, to assist the siphon head and prime the water system on starting up. One of the disadvantages of pumping from tidal water into a gravity supply conduit is that the simple constant speed pump has a variable discharge with variations in tidal level. Such variations can be overcome to some extent by constructing reinforced concrete siphons between the pumps and the conduit and by using a combination of smaller pumps.

Stations taking the water from a river or tidal source usually have the ends of both suction and discharge pipes submerged below the lowest recorded tidal level. Provided the distance between the lowest level and the highest point of the circulating water system does not exceed about 30 ft., the system will at all times and states of tide operate in a constant manner.

In one station the condensers are placed about 50 ft. above the low-tide water level and the pumping sets are provided with a driving motor, pump and water turbine all mounted on a common bedplate. The turbine is placed in the discharge pipe outlet and the power it generates assists to drive the pump. The function of the

turbine is to maintain a pressure in the upper parts of the condensers.

The inlet works should be such that large quantities of water can be taken from the river at a very low velocity, thus obviating dangerous currents or eddies.

The pumps may be located at the river side or alternatively in or near the turbine house. The site conditions and layout of station will play a big part in deciding the position of the pumping plant.

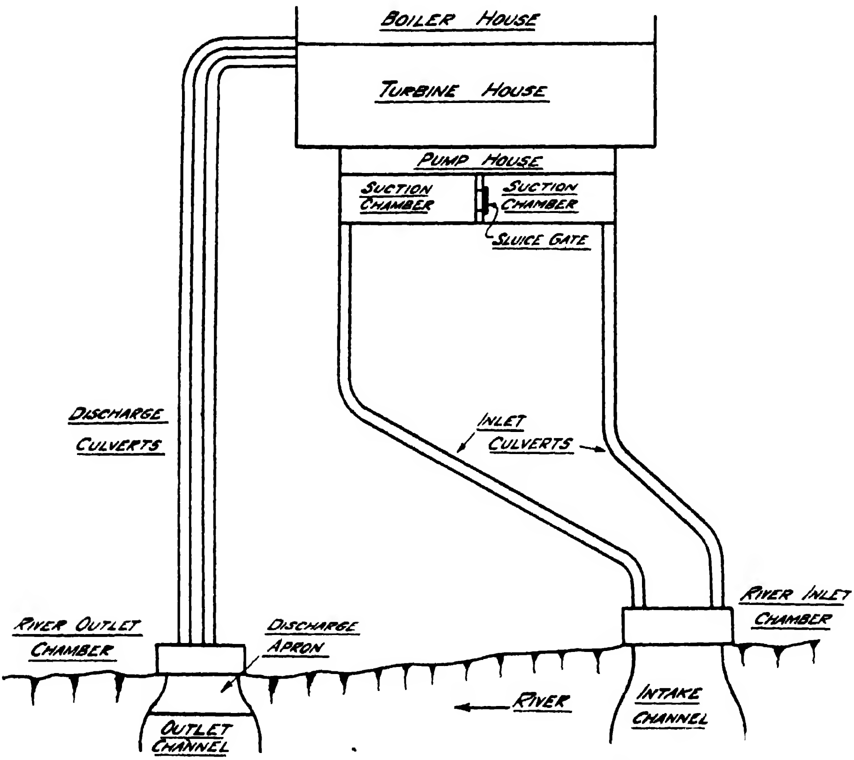


FIG. 67. Circulating Water System for 300 MW Station.

Culverts or tunnels are taken to a distribution chamber in the turbine house (Fig. 67) where the pumps are situated, or the pumps may be at the river side to pump the cooling water through pipes, or a combination of pipes and culverts, direct to the condensing plant. In one station designed for 50 MW sets the very wide range of water levels (about 52 ft.) presented a problem of some importance. The site was chosen after careful consideration of many factors relating to the flow of water in the river, the possibility of silt and other

troubles, the formation of the ground and the suitability of foundations. The site is on rock and the natural slope of the ground is upwards from the river at a steep angle.

Four large cooling water culverts are driven through the rock from the bottom of a deep screening pit situated at one end of the turbine house. These culverts are concrete lined and extend to the river. From the screening pit four culverts pass along the entire length of the turbine house, Fig. 68, at a position well below the foundations. The connections from the culverts are controlled in deep cooling water pump pits, the arrangement of the pits being

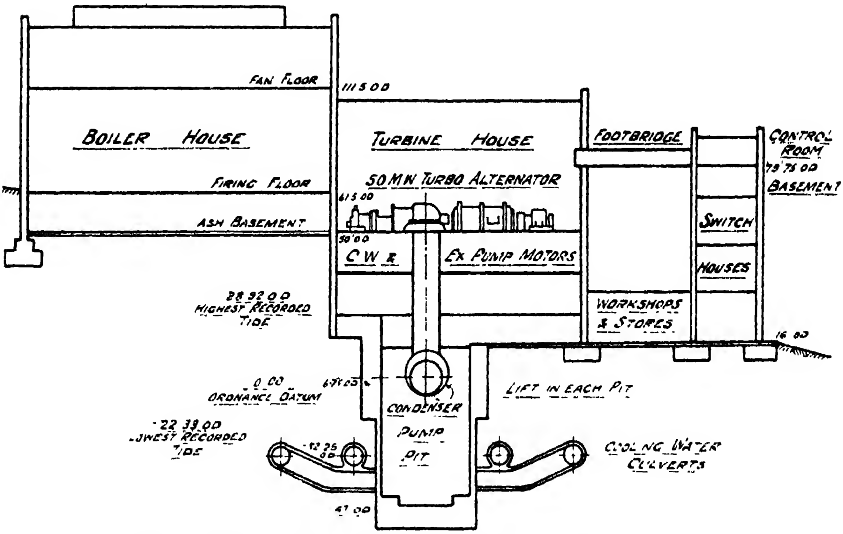


FIG. 68. Circulating Water System Arranged for Reversal of Flow.

such that one pit serves two 50 MW turbo-alternators. Each pit is situated between two turbo-alternators and on the centre line of the corresponding condensers. The connections between the cooling water culverts and the condensers are arranged so that any culvert may be used as inlet or outlet for the water. This system of connections enables relatively hot discharge cooling water to be passed through any culvert should it be necessary to do so to kill marine growth. Reversal of flow also prevents the accumulation of silt and sand.

The connections and pumps are placed well below the lowest recorded water level to ensure that the pumps are always primed. For economic pumping power the condenser is placed at such a level

that the siphonic condition of the cooling water system is always maintained. This fixed an upper limit to the height of the outlet of the condenser.

To avoid unnecessary excavation the turbo-alternators are placed at ground level which resulted in the turbine operating floor being some considerable distance above the condenser. This necessitated a steam connection 35 ft. long between the turbine exhaust flange and the condenser inlet. It will be noted that the switch house is below the turbine-operating floor, which again was due to the natural slope of the ground.

Where the power station is some considerable height above the source of circulating water some savings can be effected in both construction and pumping costs by adopting a layout on the following lines. The circulating water pumps are designed to operate completely submerged but are normally located above flood level with only slight increase in pumping compared with low-level layout. This avoids expensive excavation and sub-structure cost of locating the condensers in deep pits while keeping the turbo-alternators above flood level. The long exhaust connection between turbine and condenser is also eliminated. Two half-capacity primary pumps are used in series permitting operation of only one in the winter, when low water temperatures prevail. One pump is submerged below extreme low water and its high starting head characteristic is able to deliver sufficient for starting purposes. A booster pump—a single-suction volute type is mounted directly upon a hydraulic turbine—starts when there is enough water in the control well. The two pumps then operate automatically in series at full capacity. Advantage is taken of maximum siphon effect from the condenser drop-leg which enters the sealing or control well. From this well all circulating water is passed through the hydraulic turbine. Thus the static head from sealing well to river is utilised—75 to 80 per cent. being recovered—in reducing the work of the primary pump, with considerable saving in overall priming power. The booster pump functions until rising water renders the turbine ineffective, then the primary pump(s) works alone, producing full capacity under reduced head. Such a system has been adopted in certain American power stations by the Worthington Pump and Machinery Corporation.

It is usual to keep the velocity of the water entering the condensers (and the friction head) as low as possible consistent with the cost of civil engineering work on culverts, etc. The velocity of the water in

the discharge pipes adjoining the condensers is made rather high, probably approaching 10 ft. per second, in order that the water may carry away any air that has a tendency to settle out at the high point of the siphon. The pump inlets should be well drowned to prevent air being taken into the pumps as the result of turbulence and the condenser outlets should also be sealed and arranged to reduce turbulence to a minimum. Where pipes and culverts are underground, the worst possible loading should be determined and in the design of reinforced concrete culverts external earth pressure, flood pressure and head pressure of the pumps should be taken into consideration. In one station the worst load was found to be that due to the head of the pumps and the culvert was designed to meet this condition, the pressure per square foot on the walls being 2,600 lb. Shrinkage stresses were allowed for by providing 0·3 per cent. longitudinal steel and when casting the culverts a joint about 18 in. wide, with reinforcement continuous across it, was left every 30 ft. After the concrete had thoroughly matured these joints were filled in. This was done to enable the concrete to contract in sections of 30 ft. before being made into a continuous duct. When filled with water at full pressure no leakage was found.

Means should be provided for sectionalising during emergency or maintenance periods.

An alternative arrangement for reversal of flow is shown in Fig. 69.

In an endeavour to obtain the maximum possible advantage from siphonic action on the circulating water, with its corresponding reduction in pumping costs, in one station it was necessary to place basement level as nearly as possible at lowest river level. This would have involved expensive foundation work to withstand the pressure of the water at time of flood. The river in this case was subject to a 25-ft. flood rise. An intermediate position was, therefore, determined by calculations, at which the saving on pumping rather more than balanced the capital charges on foundation work. The turbine house is placed in a reinforced concrete chamber, the floor of which is about 10 ft. above lowest river level. At this elevation it was reckoned that such advantage from siphonic action (Fig. 70) as would ensure a considerable reduction in the cost of pumping the circulating water could be obtained. The pumps discharge water under pressure along concrete ducts 670 ft. long to the condensers, from whence the water will gravitate siphonically to the river. A 60 per cent. siphonic effect is anticipated, but a figure of 80 per cent. is probable. To obtain this result quite a lot

of planning was necessary. The twin discharge pipes are rather smaller in diameter than usual, the reason being that the maximum

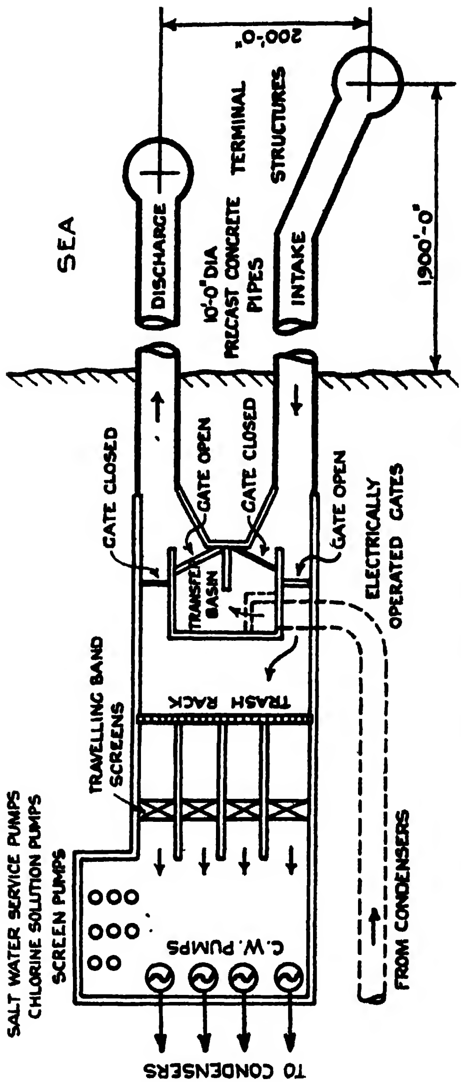


Fig. 69. Circulating Water System arranged for Reversal of Flow.

siphonic effect is more certain if the velocity is kept up and the pipes are full of water. Emission of the discharge is so arranged that there is a minimum of turbulence. The water issues first in a downward

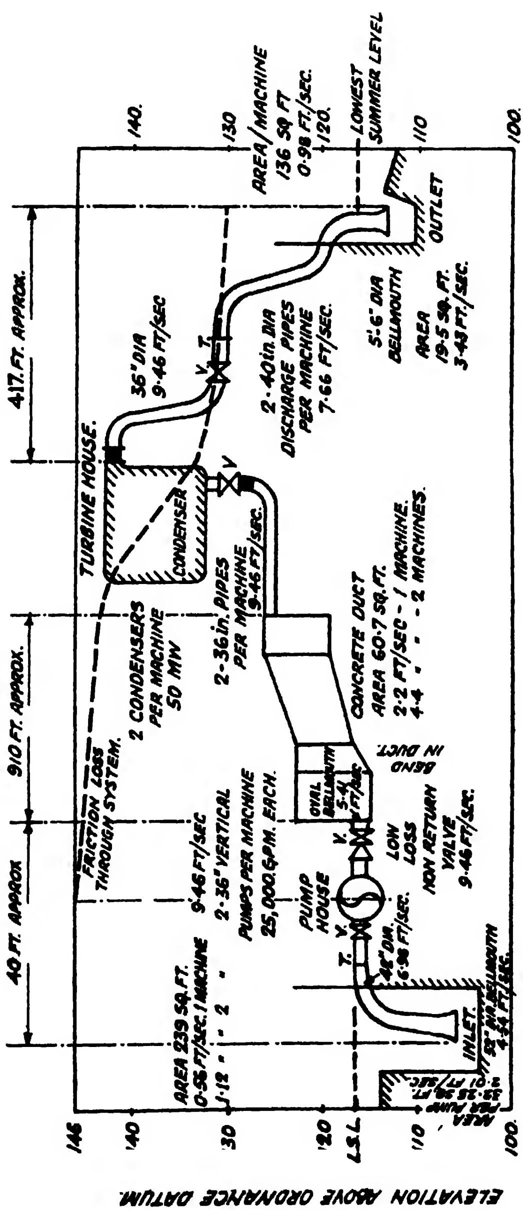


FIG. 70. Diagrammatic Sketch of Circulating Water Intake and Outlet.

direction from a bell-mouth which is well drowned beneath a considerable head and plays against a cone: it is thus reflected upwards round a fairly wide circle.

Intakes, Screening and Suction Chambers. In large stations these entail considerable civil engineering work, and where river coaling is adopted precautions should be taken to prevent damage by colliers. Timber fenders are fitted to the outside faces of the intakes.

Each screening chamber should be arranged so that it may be isolated by means of hand-operated penstocks or alternatively sluice gates to facilitate cleaning and repairs.

The suction chamber should be common to all pumps and all screen chambers, but means should be provided to enable it to be sectionalised and emptied.

Tunnels, culverts and suction chambers can impair pump per-

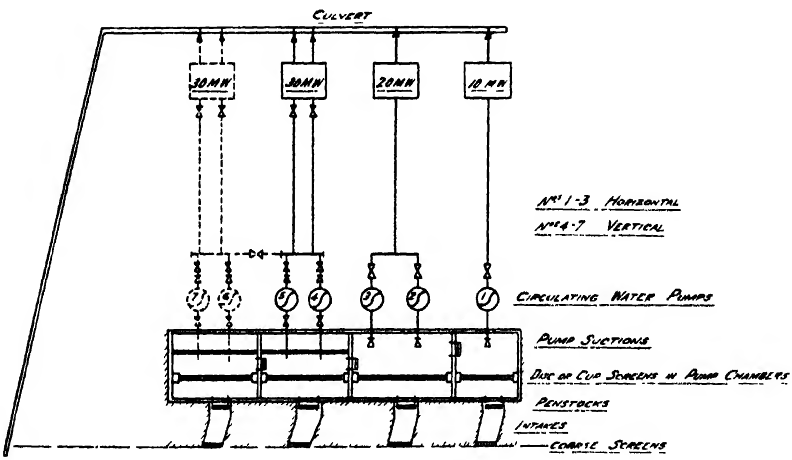


Fig. 71. Circulating Water System for 90 MW Station.

formance unless care is exercised in their arrangement. Eddying, if not eliminated, will cause cavitation and rapid wear of impellers as well as liberate air to damage the condenser tubes.

The intakes, screening and suction chambers may be covered with removable creosoted timber and certain portions with chequer plating or open-grid steel flooring. When solid flooring is laid adequate air spaces should be provided. Poisonous gas from decayed seaweed has been known to cause loss of life in circulating water pits and care is always required when draining off and entering chambers and tunnels. Men can be overcome by the fumes.

It may be necessary to place a track over the intake chambers to allow a jib crane to grab the silt from the river, intake and screen chambers. The intake flume can be roofed to prevent river bank

erosion being carried into the intake under flood conditions and with this construction the screening chambers stand high of normal river level.

In practice entrance velocities of 1 ft. per second to 2 ft. per second have been satisfactory in large stations, whilst in small stations velocities approaching 4 ft. per second have been trouble-free.

Much will depend upon local conditions, but wherever practicable the entrance velocity should be kept as low as possible. A clear waterway should be maintained in front of the coarse screens in case a ship may be lying on the river bed at low tide and obstruct the direct flow of water.

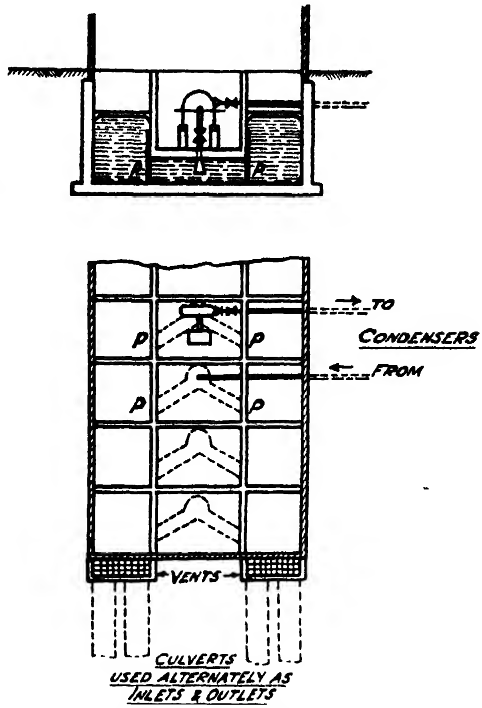


FIG. Pump House Layout for Duplicate Screening Plant.

The culverts are sometimes arranged in such a manner that it is possible to reverse the flow and so prevent silting up with mud or sand. This arrangement may necessitate the use of two screening chambers (Fig. 72) and plant. The higher first cost is partly off-set by the reduced charges

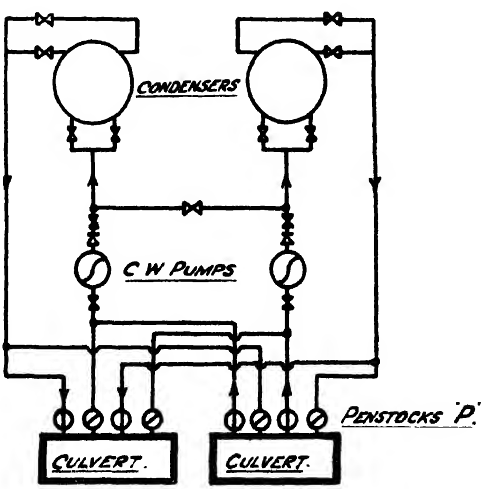


FIG. 72A. Diagrammatic Arrangement of Fig. 72.

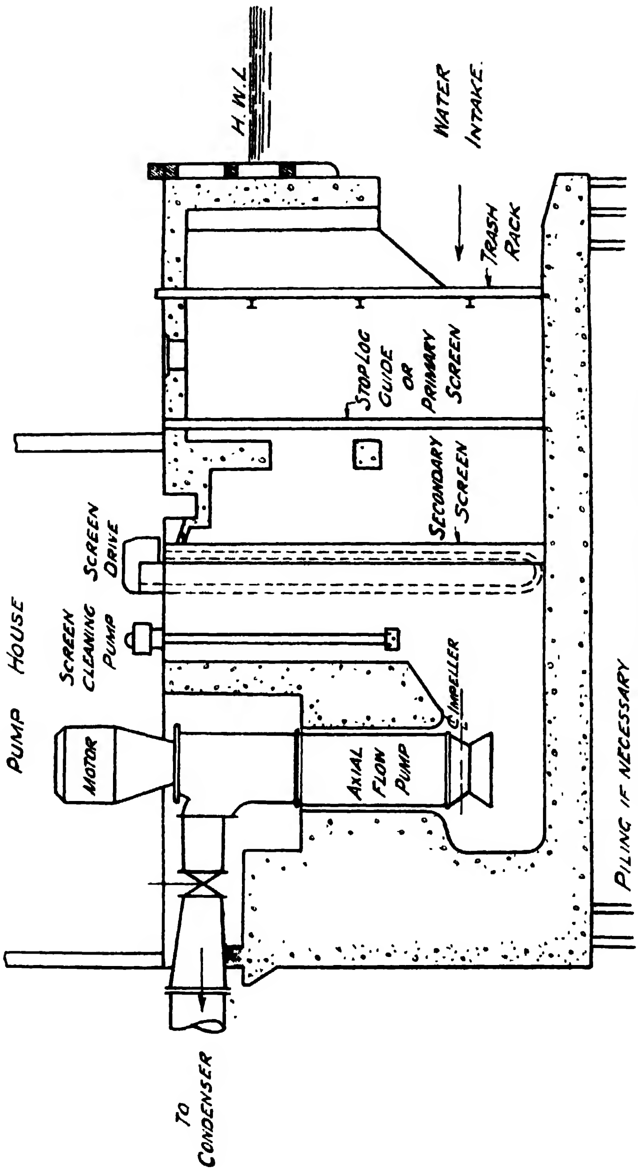


FIG. 73. Circulating Water Intake Layout.

for cleaning. Fig. 72A shows the pumping and piping layout.

If the station takes its cooling water from the sea and is affected to any great extent by the tides, then it will almost be essential to provide for reversal of flow in the culverts and also include two

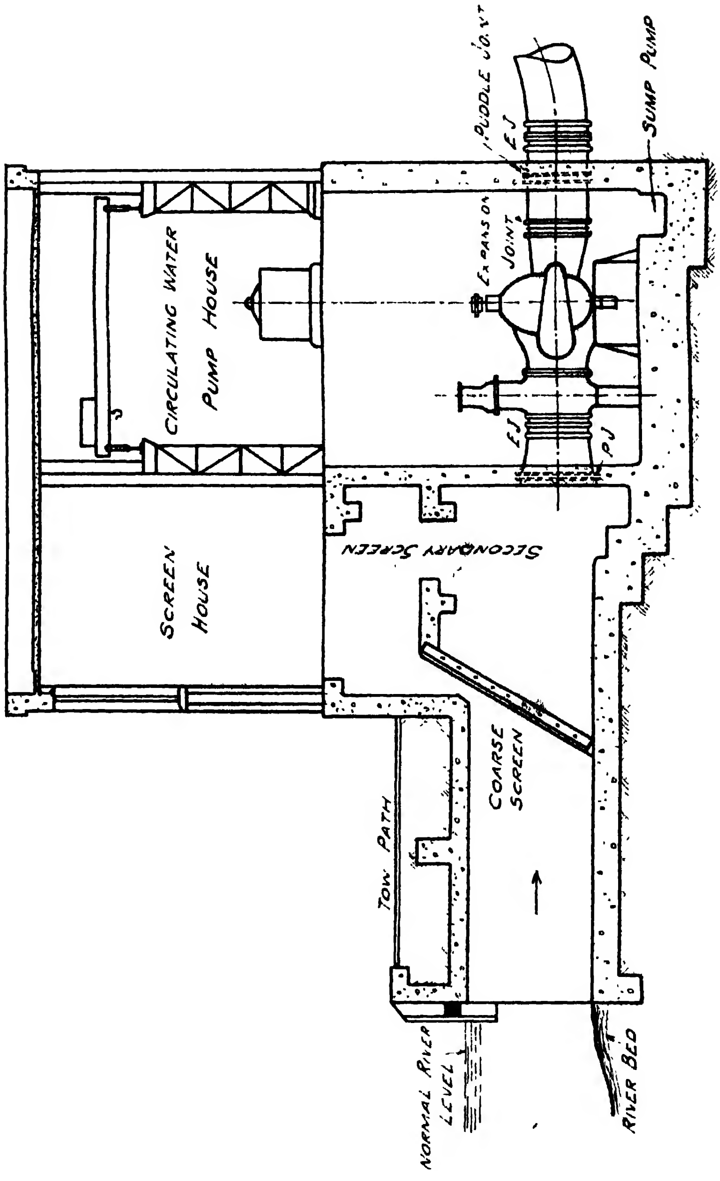


FIG. 74. Circulating Water Intake Layout.

screening plants. In tropical climates it may be justifiable to place the cooling water inlets some 20 ft. or more below sea-level to obtain a 9° F. lower temperature.

Figs. 73 and 74 indicate two intake layouts.

Intake Culverts. The intake culverts from the screening chamber to pump suction chamber may be of circular, horseshoe or rectangular section, the cross sectional area being governed by the amount of

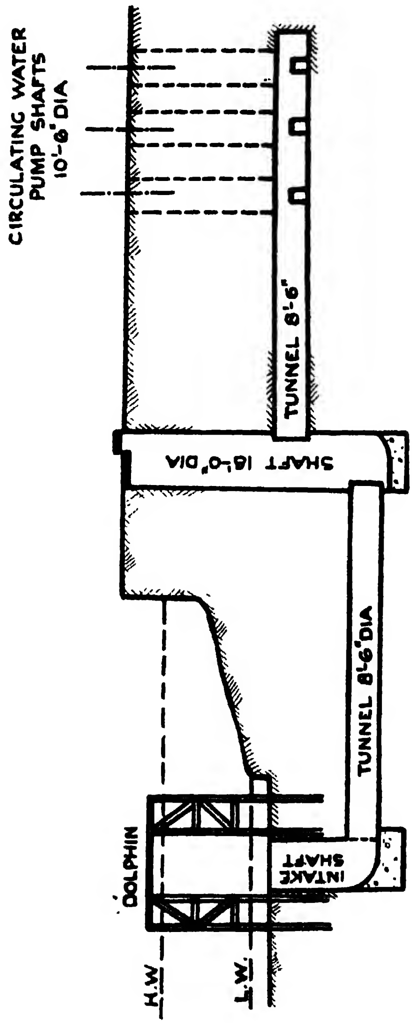


Fig. 75. Intake Culverts and Shafts.

water required. In dock-side stations the condensing water may be obtained from one dock and returned to another by means of low-level tunnels. Fig. 75 shows one arrangement employing tunnels. If the vertical opening provided rises above the level in the dock basin it may be found that the cooling water is liable to contamina-

tion from oil and flotsam coming from the docks. This can be overcome by curtaining-off the upper part of the opening in such a way that there is always a minimum depth of 2 ft. of water over the intake.

At one station the shafts at the station end are 300 ft. deep and at the docks 250 ft. and 240 ft. deep, the difference in levels being due to the gradients given to the tunnels for the purpose of drainage during construction. The shafts are 14 ft. in diameter and the horseshoe-shaped tunnels driven through solid rock are about 9 ft. diameter and lined with 9 in. of concrete. The intake tunnel is ½ mile long and the discharge tunnel ¾ mile.

Another station has four (two inlet and two outlet) 7 ft. 6 in. internal diameter concrete culverts lined with brindle brick. The culverts are situated at such a depth as will maintain at least 4 ft. of water over the top of the sea ends at the lowest recorded tide. They are constructed on a constant level throughout their entire length with the exception of a section at the sea ends which for a length of 30 ft. is graded upwards on an incline of one in five. The sea ends of each pair of culverts are situated 50 ft. apart with 150 ft. between each pair. As a precaution against the accumulation of silt in the culvert mouth a shelf in the river bed about 30 ft. from the culvert was dredged. To guard against the possibility of silting, the circulating water culverts and connections are designed to allow of the flow of water to be reversed, *i.e.* inlet or outlet as may be desired. By throttling the outlet valves the temperature of the water may be raised to destroy any marine organisms adhering to culvert linings. The method of constructing the culverts involved the sinking of two temporary working shafts adjacent to the station, 12 ft. internal diameter and concrete lined, with two similar shafts iron-lined and concrete backed at the foreshore. Iron-lined working chambers 12 ft. diameter and 24 ft. long were built on the centre lines of the culverts and connected to the working shafts by short passages. From these working chambers the culverts were driven in opposite directions the work being carried out in sections 12 ft. long. The permanent screening shafts, four in number, sunk near the turbine house were also utilised as working shafts from which similar headings were driven. Considerable quantities of water were encountered between the foreshore and the sea which necessitated the construction of iron-lined chambers with air locks, the works on this section being carried out under compressed air. .

The velocity of flow in intake culverts is between 4 to 7 ft. per second. An intake from a canal (7½ million g.p.h.) had an average

maximum velocity of 5 ft. per sec. in the culverts. The canal water evolved considerable quantities of gas when submitted to a rise in temperature and high vacuum, and to maintain the best possible siphonic efficiency air pumps were installed.

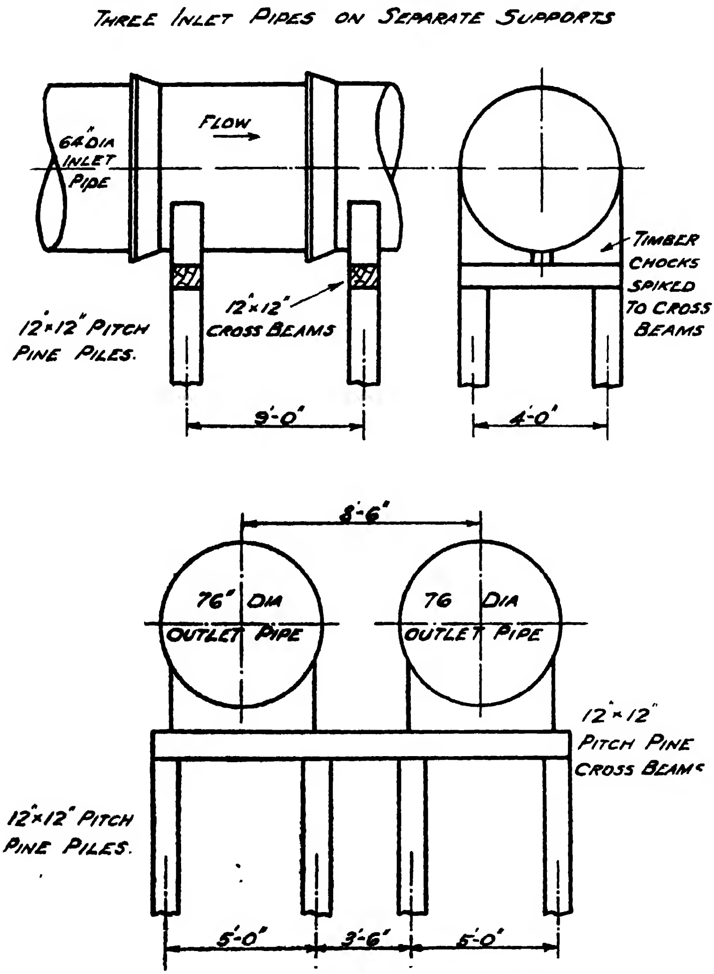


FIG. 76. Supports for Circulating Water Pipes.

Pipes are also used, and these are dealt with under the pipework section. Spun reinforced concrete pipes of 72 in. diameter have also been used. One method of supporting cast-iron pipes is shown in Fig. 76.

Outlet Culverts. These carry away the water discharged from

the condensers to outfall works situated on the river bank. The construction is similar to that of the intake culverts, with the exception that the cross-section area may be slightly larger. The maximum velocity of flow is about 8 ft. per second.

In some stations where sets of 50 MW capacity and over are installed each set has two discharge pipes (divided condenser) led separately to an outfall. For four sets there would be four outfalls at the river each being served by one set having two discharge pipes. Depending on site conditions, it would appear that wherever

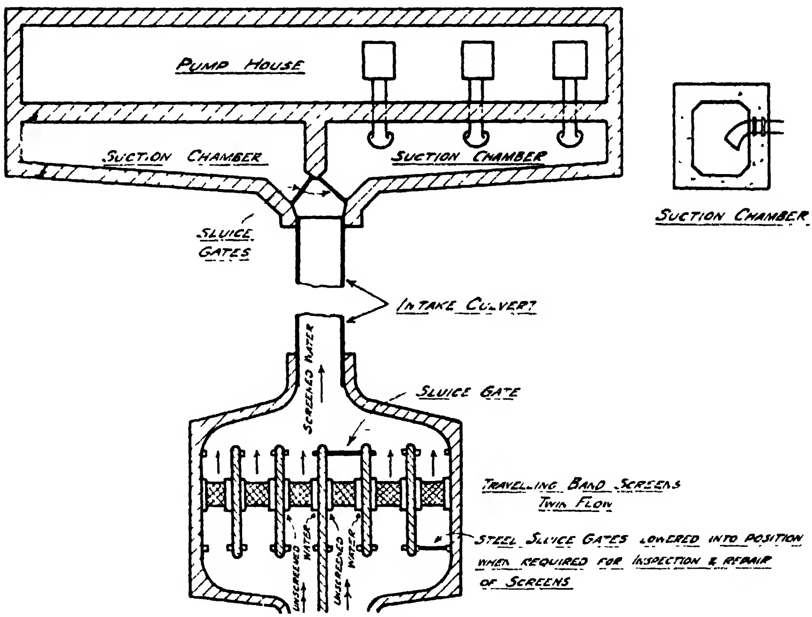


FIG. 77. Circulating Water System for a Large Station.

possible the inlet and outlet culverts should be a monolithic construction, the latter being placed directly above the former. In this way special crossings are reduced and civil engineering work is cheaper.

Outlet Chamber. The velocity of the water discharged to the river should be reduced to a minimum. In large stations, where some 12,000,000 to 14,000,000 gallons per hour of water are used, due consideration should be given to this matter. The openings should be such that a uniform discharge is obtained, and the velocity should never exceed 1 ft. per second. In smaller stations where conditions permit, this figure may be exceeded without

harm. The outlets are sometimes arranged to be shut off from the river by means of penstocks, sluice gates or dam boards. By partially closing the outlets, the water velocity may be increased to

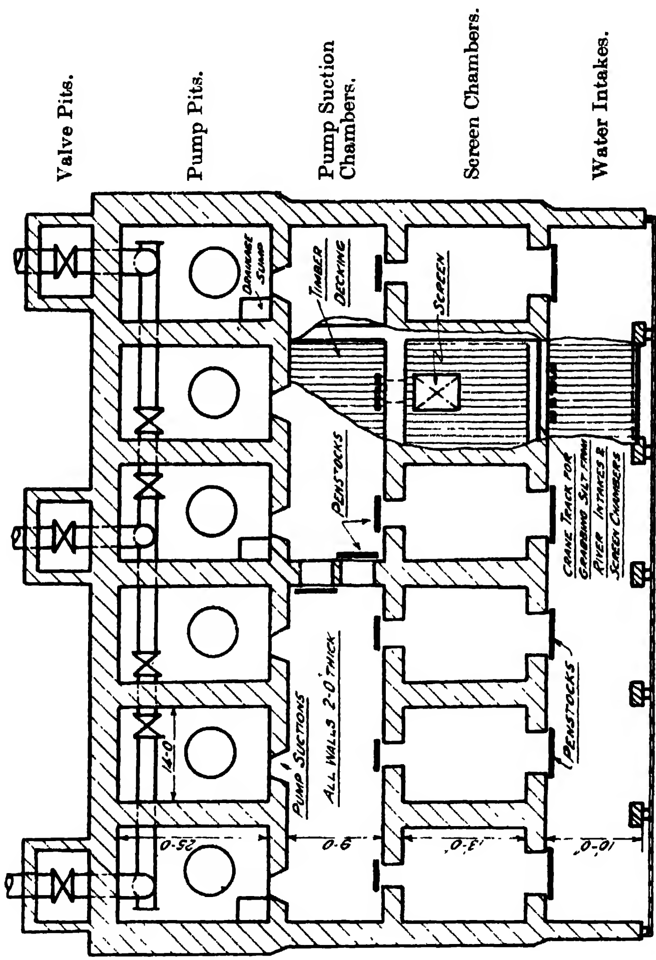


Fig. 78. Circulating Water Pump House Layout (Plan).

clean any portion of the outlet apron or discharge works. Here again colliers may cause damage unless precautions are taken.

Where site conditions are such that the depth of the water-bearing strata is too great to permit the use of compressed air, the ground may be frozen to the necessary depth by sinking a ring of circulating pipes through which a freezing mixture is passed. This applies to the sinking of shafts, etc.

Screens are necessary for screening the water passing into the circulating water system, to prevent damage to pumps and valves, also choking of the condenser and cooler tubes. Screens are one of three classes, namely :—

(1) Fixed, (2) Travelling, (3) Revolving.

The first is used as a primary screen to protect the more expensive mechanical type or where only coarse screening is required. The inlet works should have some form of coarse screen to prevent the ingress of large floating *débris*, etc., to the screening chamber. The velocity of water through the screens should be kept within reasonable limits, as large submerged articles may be drawn against the screens, resulting in starvation of the pumps. To reduce the velocity the area of screen should be as large as possible.

These screens are made from timber, wrought iron or mild steel bars, two examples of which are :—

(1) Coarse timber grillage with clear pitch of 6 in. between vertical bars.
(2) $\frac{3}{4}$ in. diameter mild steel bars at 4 in. centres secured by flat bars of 3 in. × $\frac{3}{8}$ in. cross section made into panels convenient for handling.

The selection of material for this purpose has been given special attention, particularly with reference to corrosion. Some of the materials considered are :—

(1) Copper-bearing steel.
(2) "Armco" iron.
(3) Mild steel with protection of electro-deposited cadmium.
(5) Wrought iron.

The last is the most economical and is generally quite satisfactory. Mild steel without any protection has been used, and appears to have given satisfaction over a long period of years.

Both fixed and travelling screens of galvanised steel may be afforded cathodic protection by a selenium rectifier and a graphite anode ground bed system.

Easy access is desirable to permit cleaning and repairs to the screens. Small fixed coarse screens are normally hand-raked but mechanical raking machines may be used where the quantity of *débris* is excessive.

Where water is drawn from the sea, tunnels are laid below the sea bed with shafts at either end, each of which may be used as an inlet or outlet. The construction is similar to that used for shafts and tunnels on underground railways, the cast-iron segments being filled with concrete and given a smooth finish. The tops of the shafts in the sea should be such that a cover or sealing cap can be placed in posi-

tion and the tunnels emptied for inspection, repair and cleaning. For normal working a gunmetal screening grid lies on a machined gunmetal ring that is fitted to the shaft. This coarse screen prevents the ingress of large floating *débris* to the shafts and tunnels. The

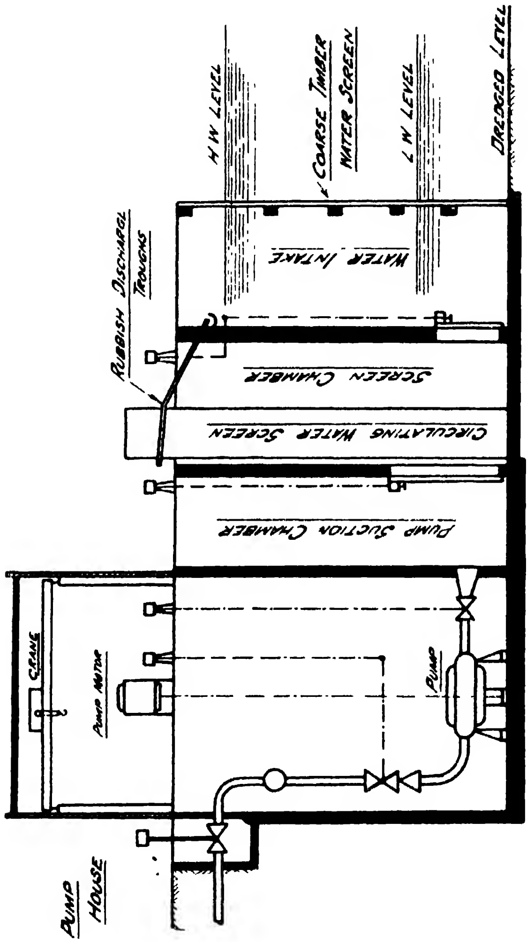


Fig. 78A. Sectional Elevation (Fig. 78).

shafts and tunnels must comply in all respects with the regulations of any harbour or coastal authorities.

At the lowest observed tide there should be an adequate covering of water (4 to 8 ft.) and a beacon will be required over each shaft. The pump house is over the land shafts, and the latter each have a coarse screen which is handled by the pump-house

crane. Motor-driven rotary strainers are fitted between the shafts and the pump suction chamber.

In one installation lignum-vitæ cut into V-shaped blocks was used as the straining medium.

At the sea end of each culvert wrought iron grids have also been used and greenheart doors fitted so that the culverts can be emptied for inspection and cleaning. Near the turbine house the culverts can be intercepted by screening shafts (17 ft. dia. and 66 ft. deep) which connect (Fig. 79) each culvert with a screen house situated on the surface. The lower section of each shaft is slightly enlarged and shaped to ensure an easy flow of water. The junctions between the shafts and culverts are formed with granite bell-mouths and vertical granite cut-waters are provided on the two screens in each culvert. The screening plant is capable of dealing with the requisite quantity of circulating water at all levels of tide over a range of

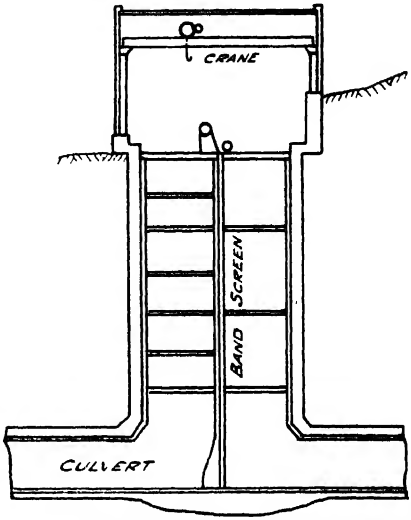


FIG. 79. Section of Culvert and Screening Shaft.

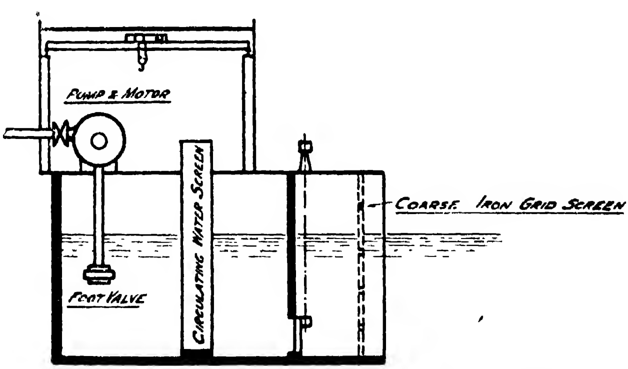


FIG. 80. Circulating Water Intake for a Small Station.

52 ft. To ensure uninterrupted passage of outlet water each screening shaft has an overhead crane to lift the screens into the shaft and above the level of the culvert.

Travelling screens may be of the twin-flow or uniflow types and are used where there are large variations in water levels. Revolving screens of the disc, cup and drum types are used where the variations are small. The cup screen is a modification of the disc type in which the screening medium is arranged circumferentially and forms the periphery of the "cup." A greater screening area is obtained and where chamber space is restricted holes may be provided in the refuse lifting trays to release any air.

Another type of rotary screen or strainer which is in the discharge pipe to the condenser consists essentially of a wheel enclosed in a watertight casing. The wheel is built up of strainer grids or panels and revolves at about 1 r.p.m.

A cleaning compartment is provided where a portion of the straining wheel is exposed to a jet and cleaned during rotation. This pipe-line screen has been used on circulating water pumps having an output of 1,250,000 gallons per hour, is independent of water levels, reliable, economical and accessible.

In the drum type the drum revolves on the circulating water-pump suction pipes, which serve as trunnions. The complete installation is located in the river bed, and foundation work is reduced. The only foundation work required is the piles in the river bed, the entire screening plant, including driving gear, being supported on the piles. This screen is recommended on sites where it is difficult to build concrete chambers for housing the screening plant, and although the initial cost of the screens is rather high, the cost of installation is reduced.

The mechanical or secondary screens should be of the self-cleaning pattern of robust construction, and preferably with individual drive where large units are employed.

The materials used should be durable and withstand any corrosive action and in this respect the galvanising of the screening panels and sherardising of mild steel sections appears to be satisfactory.

Circulating water frequently contains large quantities of leaves, twigs, straw, hair, floating wood, etc., although much depends on the locality. In some stations the condensers, air and oil coolers have been choked by periodical invasions of multitudes of small eels. Certain rivers in South Africa have a weed (water hyacinth) which can cause trouble. So long as it floats there is no practical danger, but if it sinks either because of chemical spraying or due to frost it can be drawn into the screen chambers and pumps and cause much damage. A mechanical system of clearing is better than chemical

spraying, as the latter left a stinking mass which floated on the river some considerable time.

The water passing through the screen deposits the *débris* on the outer face, which is carried to the top of the chamber. At or near the top of the travel or circular path are fixed fan-shaped water jets which deliver water under pressure and wash off the *débris* from the outer or inner face, as the case may be. The *débris* falls into a trough and is flushed away to a perforated refuse pit or returned to the river.

The cleaning water pump and screen drive may both be driven by the same motor but separate drives are preferable, as pump

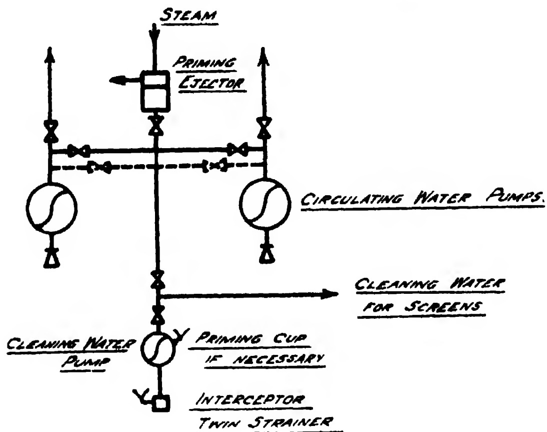


Fig. 81. Cleaning Water to Screens and Pump Priming.

choking may necessitate stopping the screen drive until it is disconnected. Cleaning water may also be taken from the main circulating system. In large installations it is usual to provide two separately driven pumps, one being retained as standby. As a precaution against choking of the pump and jets, each pump can be arranged to draw its water through a self-cleaning twin strainer, whilst the inclusion of an interceptor on the pump suction ensures correct priming.

The screens may be arranged for a number of speeds by including a variable speed motor or gear box and in this way the screens are speeded up and freed from large accumulations of leaves or other floating *débris*.

During cases of extreme emergency or screen failure one of the screens may be withdrawn and coarse screened water allowed to pass to the pump suction chamber.

It may be unnecessary to run the screens continuously except during certain seasons of the year, but periodical running and attention is necessary to keep the plant in working order.

The screens may be fitted with automatic by-pass gates, and in the event of blockage of the faces the water passes *via* the gates and prevents collapse. The screen has a steel gate below water level, which faces the incoming water ; under emergency conditions the gate automatically opens and allows water to pass through the centre of the screen frame. The opening is brought about due to a predetermined difference in water pressure between the unscreened and screened sides of the band. Hand operation is also provided and there is no possibility of starving the circulating water pumps. Some idea of the sizes of water screens will be gathered from examples of two plants :—

(*a*) Band screen.	Maximum capacity 3,000,000 gallons of river water per hour when immersed 12 ft. (lowest water level).
	Variation in water level, 29 ft.
	Overall length, 50 ft.
	Speed, 6 to 15 ft. per minute.
(*b*) Cup screen.	Maximum capacity 1,500,000 gallons of river water per hour when immersed 5 ft. (lowest water level).
	Variation in water level, 7 ft.
	Diameter of screen, 15 ft.
	Speed, 9 ft. per minute.

Figs. 77 to 81 indicate some usual arrangements.

Cooling Tower System. Where the cooling water from a river or canal is limited it may be essential to provide cooling towers to conserve the water. Due to losses caused by evaporation, leakage, etc., it is still necessary to have water available to compensate for this loss. Assuming the loss to be 1 per cent., then the make-up water required per hour in a 300 MW station would be between 150,000 to 170,000 gallons per hour. This make-up may be taken from a river, sewage outfall or, in times of emergency, from a town main supply, the latter being rather expensive.

The system is similar in many respects to the river circulating system, the main difference being that the cooling water is alternately warmed and cooled and circulated continuously.

The final inlet temperature to the condensers depends to a large extent on atmospheric conditions, and the temperature of the cooling water is much above that of a river. Typical layouts are shown in Figs. 82 to 84.

The cooling water required to carry off a given amount of heat is therefore much larger when cooling towers are employed. Further,

the pumping power is considerably increased and more space is necessary to accommodate the pumps. Site conditions usually determine the layout to be adopted. A reservoir, suction chamber

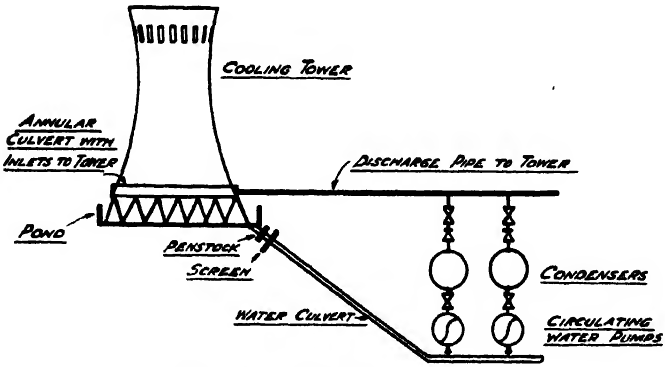


FIG. 82. Cooling Tower System.

or culvert is arranged to adjoin the turbine house and may form part of the floor upon which the circulating water pumps are placed. The suction culverts should be proportioned to obviate any possi-

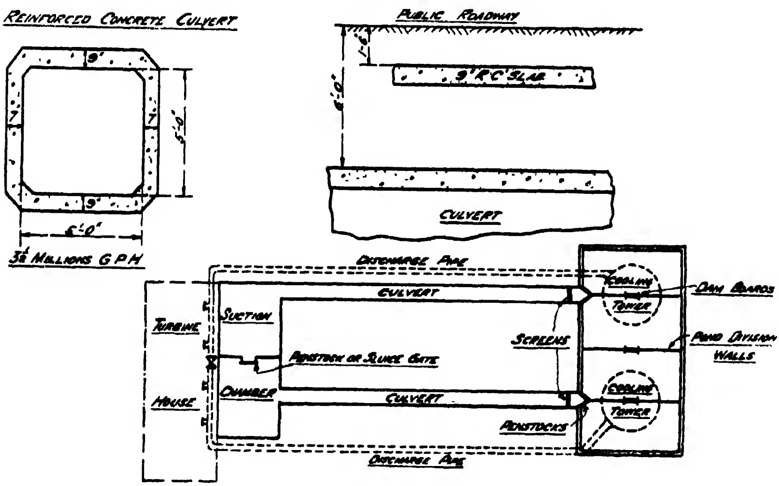


FIG. 83. Circulating Water System with Cooling Towers.

bility of a vortex which will result in circulating water pump troubles. The suction chamber is connected to the cooling towers by means of culverts, penstocks being fitted at the tower end to isolate or regulate the water flow to the chamber. Manually operated penstocks are

quite suitable. The cooling tower pond level should be sufficiently high above the chamber level to give the necessary flow. Considerable quantities of sludge collect in the culverts and suction chambers and periodical cleaning is necessary.

To enable cleaning to be carried out without closing down the station, the suction chamber culverts may be sectionalised by sluice gates so that any turbo-set may be taken out of commission. The position of the sluice gates will depend upon the disposition and capacities of the turbo-sets and cooling towers. The sluice gates may be of steelplate construction faced with timber to which hemp ropes are secured.

A portable pump may be used for culvert cleaning, the sludge being mixed with water and the resulting slurry discharged through

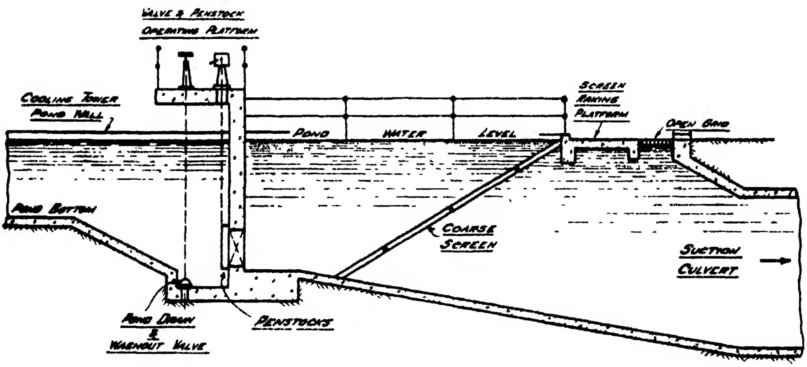


Fig. 84. Cooling Tower Outlet.

a pipeline to a dump. The pump has flexible lengths of hose for the suction and discharge connections. In order to rid the system of any *débris*, such as wood chips, rags, etc., which collect during the construction work, a screen should be included at the tower end of the culvert.

Cast iron is more suitable than mild steel for these screens, although $\frac{3}{8}$ in. mesh expanded metal screens have been used. Duplex screens of $\frac{1}{2}$ in. mesh × 14 S.W.G. copper wire cloth are also in use. If the water carries large quantities of paper, small wood chips, etc., particularly during the initial filling up, a series (two or three) of fine screens at the entrance to the suction chamber end of the culvert are justifiable. Should the towers be situated near trees, trouble may be experienced from falling leaves if fine screens are excluded. A screen at the suction chamber or culvert entrance also prevents

anyone having fallen into the pond from being carried into the suction culvert.

The make-up water should be discharged into the ponds of the cooling towers, so that it is screened before passing into the suction chamber. If the make-up be taken from a river, the screening plant will be much less for a cooling tower installation. Provision may be made to take advantage of excess water flow in the river by introducing it into the cooling water system and discharging an equal amount of warm water from the system into the river without this overflow passing over the cooling towers.

Where sewage effluent is used, care should be taken to ensure that the cooling water is free from destructive acids otherwise trouble may be experienced with condenser and cooler tubes.

Sewage effluent has caused, or it is thought to have been chiefly responsible for, the emission of large quantities of froth from the circulating water culverts. Probably the entrained air also assisted in the production of this irregular phenomena, which caused much inconvenience. Brick ventilating shafts were built at numbers of points in the culverts, and water sprays were included to keep down the froth.

Chlorine treatment plant is also installed at the inlet of the sewage effluent.

Spray Cooling Ponds. The simplest form of circulating water cooling is the open pond into which the warm water from the condensers is discharged and cooled by contact with the atmosphere on the pond surface. Atmospheric conditions play a large part in the degree of cooling obtained, further, a large pond area will give a larger degree of cooling, whilst a deep pond will permit of a cooler supply of water to the pumps. Spray cooling ponds are used in small stations.

Some of the factors which influence the rate of heat dissipation from a cooling pond are : initial temperature of the water entering the pond, atmospheric temperature, relative humidity, wind velocity, solar radiation, earth temperature and atmospheric pressure. The two latter items can for all practical purposes be neglected.

The surface area required will depend on the location, and the ponds should be placed where the prevailing winds are not obstructed by buildings, etc. The evaporation will be less in cold weather than in hot.

To limit the sizes of ponds, the water to be cooled is distributed over the ponds by pipes and sprayed through nozzles. The pressure is sufficient to break up the water, causing it to fall in the form of fine spray. In this way evaporation is expedited by increasing the

surface in contact with the air. A considerable percentage of water may be carried away in suspension in the air when high winds prevail in addition to the loss due to evaporation.

Sea Water System. This system is similar in all respects to the river and canal system. In one station, because of the saline nature of the circulating water, all screen guides, piping, condenser water boxes and pump casings were fabricated from 2 per cent. nickel-iron alloy, which has shown greater resistance to graphitisation than ordinary cast-iron in brackish waters. The slight increase in cost is justified by its longer service life. All ferrous metal surfaces were Parkerised before being painted.

There are instances where coral growth has taken place and this has been attributed to the deposition of coral from ships' bottoms carried from coral-bearing water.

Mussel growth in the circulating water pipework and culverts impedes the water flow, and unless precautions are taken to prevent undue accumulation serious trouble will be experienced. Mussels can breed at an alarming rate in the pipes, culverts and channels. In one station during a single cleaning period it was quite common to remove some 400 tons of mussels. Continuous chlorination eliminated this trouble. Spawning took place in winter as well as in summer and once the spawn became established and growth commenced chlorination did not appear to prevent further development.

Various methods have been tried, some of which are :—

(*a*) Chemical treatment of water.
(*b*) Raising the temperature of water.
(*c*) Periodical changing of the flow in the pipe lines.
(*d*) Maintaining a relatively high water velocity.
(*e*) Inserting a cleaning ball in pipe line.

Mussel growth may even take place in the condenser water spaces and end boxes, and under favourable conditions a mussel grows to a length of 3 mm. in about four weeks from the time of adherence of the floating spawn to the surface.

It is claimed that method (*b*) is very effective and simple to carry out, providing the necessary pipework cross-connections are included and the intake and discharge pipes or culverts can be transposed. The by-pass or re-circulating connection should preferably be as near to the sea end of the pipe lines as is practicable.

The heated sea-water is circulated repeatedly until a temperature is reached which is fatal to the young mussels and spawn.

It has been found that mussels cannot survive on sea-water at a temperature of 100° F. to 120° F. for more than one hour or there-

abouts. The time of survival at any temperature increases with the size (or age) of the mussel and for a mussel of 3 mm. in length a temperature of 110° F. is fatal after about half an hour's exposure. The reproductive cycle ceases when the temperature of the sea-water falls below 60° F.

Re-circulation may be effected by by-passing (Fig. 85) the

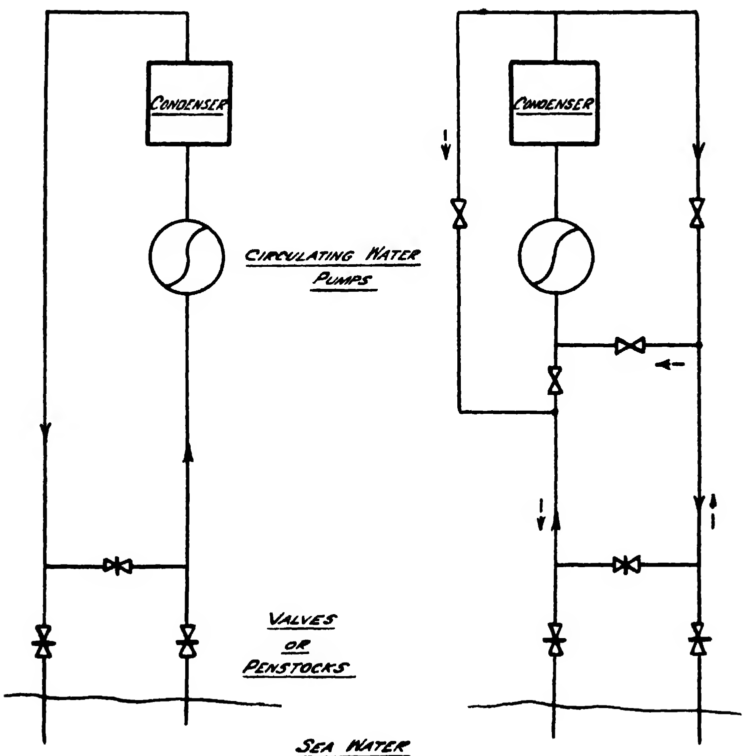


Fig. 85. Typical Layouts for Re-circulation or Reversal of Circulating Water Flow.

discharge back to the inlet until the desired temperature is obtained. This temperature can then be maintained by regulating the amount by-passed and the amount of cold inlet which is added. In this way the intake and discharge pipes between the station and the by-pass will be subjected to the desired temperature and the water in the remainder of the discharge pipe or culvert will gradually be raised to this temperature, as the surplus which is not by-passed finds its way to the discharge end and expels the cooler water from the pipe.

The time taken to complete the process depends on the total length of the pipework, the position of the by-pass and the time necessary to attain the desired temperature.

The mussels do not become dislodged immediately after treatment, but may take some days before decomposition takes place, when they readily fall away. It has been suggested that the complete circulating water system should be so treated once every four weeks during the spawning season, which normally extends from March to October, inclusive.

All sections of the pipework system are regularly treated, otherwise, if sections are neglected for long periods, when treated they release mussels and growth large enough to choke condenser tubes.

The layout of the pumps, piping, culverts, valves, etc., should be such that changeover or by-pass operations are simple.

In the case of culverts, provision should be made for cleaning, the necessary isolating sluice gates being included.

With pipe lines a number of ample-sized cleaning and inspection doors should be provided. The capital cost is higher than for chlorine treatment, but the fixed charges on this capital are less than the annual cost of the supply of chlorine for one station.

In some installations sterilising the water by chlorine treatment has proved effective in keeping the deposition of spawn down to a minimum. It has been suggested that traces of silver in circulating water are more effective than chlorine in the suppression of marine growths. The silver is imparted to the water by means of suitable silver electrodes and, used with discretion, it is possible to destroy these growths at very little cost, since it is only necessary to use it periodically whereas chlorine treatment may be continuous, depending on the conditions. The advantages of silver treatment are the very simple and comparatively cheap form of equipment, whilst pipework, tanks, etc., associated with chlorine plants are unnecessary.

The insertion of a wood ball in the pipe line has proved effective in maintaining a clean line by freeing it of mussel growth. The ball is small enough to permit of it passing along the line with two or three main pumps running. Provision has to be made for inserting and removing the ball from the pipe line which in some cases is only once per year. An inflated rubber ball with enclosing chain having a diameter slightly greater than that of the pipe is useful. The ball is inserted in the pipe and carried through by water flow, cleaning and scouring as it moves along.

Water Treatment. Examples of growths or deposits taking place

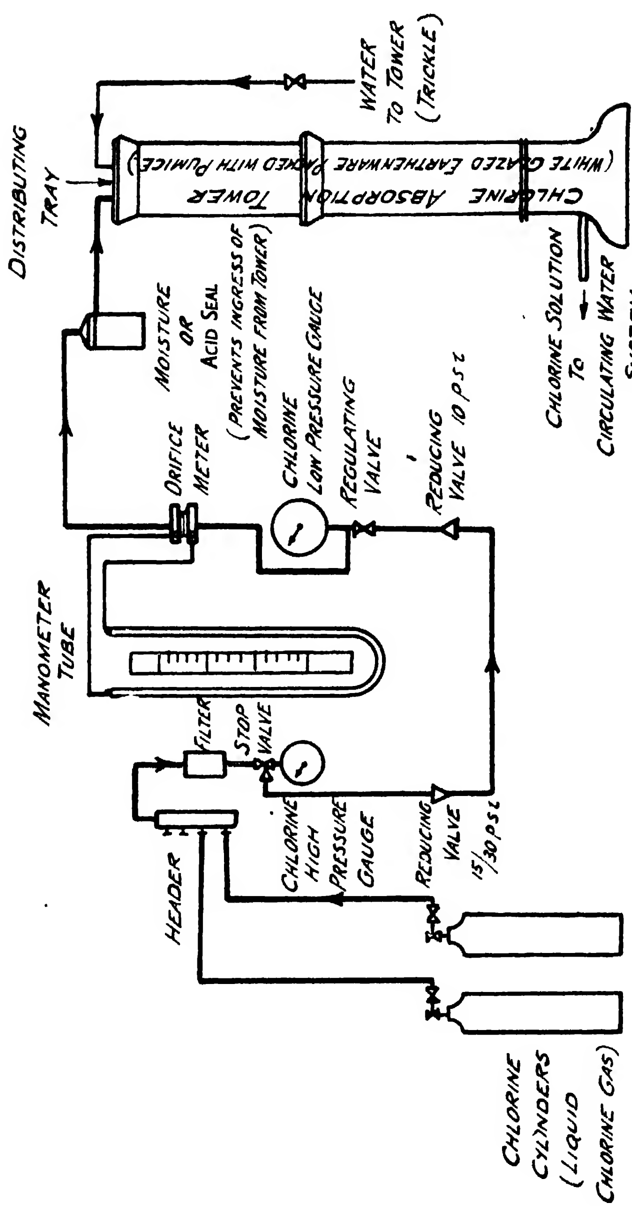


FIG. 86. Chlorination Plant (Paterson Eng. Co. Ltd.).

in river and canal systems have been found particularly where process works discharge into the river, from which cooling water is drawn. These take place in spite of the fact that the discharge from

the works has been previously treated to comply with the River Board Regulations.

Cooling water from large and small rivers and canals almost invariably contains vegetable matter and micro-organisms known as algæ, and as the temperature of the water increases these organisms multiply. Cooling tower systems. especially where sewage effluent is used for make-up, may also be subject to like growths. A slimy lining is formed on the tube surfaces to which suspended particles in the cooling water readily adhere and in a short time reduce the heat transfer efficiency. Chlorinating plant is designed to prevent the accumulation of low heat transfer deposits on the condenser tube surfaces which arise from the cooling water, thereby ensuring maintenance of optimum vacuum and economy in fuel consumption and permitting the generating plant to be run to a continuous operating schedule by obviating the need for periodic shut-down for condenser cleaning. The intermittent desliming process, which economises in chlorine consumption, is effected by applying the chlorine at intervals with the object of destroying and dislodging any micro-organisms which may have adhered to the tube surfaces between treatments, but before any appreciable development or attraction of suspended matter from the water has taken place.

The treatment of circulating water with a small proportion of chlorine gas checks the development of the organisms and preserves the tubes in a clean and efficient condition which is conducive to high station efficiency.

The process has been applied to sea systems to prevent mussel growth in pipes and condenser circuits. It is not always possible to use chlorination on river systems owing to the fishing rights held by river authorities.

The growth of algæ and weeds (green and slimy) upon cooling tower stacks can also be checked by chlorine treatment.

Fig. 86 shows a typical form of chlorine treatment plant.

The Paterson Eng. Co. have chlorine plants in three general types :—

(1) "Pulser" : 10 lb. of chlorine per 24 hours.
(2) "Manometer" : over 10 lb. of chlorine per 24 hours.
(3) "Automatic" which controls the rate of chlorination addition to the water automatically in direct ratio to the main flow passing through a Venturi meter.

0·5–6·0 lb. of chlorine per hour—50,000–600,000 galls. per hour,
0·5–30·0 lb. of chlorine per hour—50,000–3×10^6 galls. per hour,
on the basis that 1 part per 1,000,000 is required, but in practice a figure of 0·5 part per 1,000,000 or less is required.

Characteristics of chlorine gas are :—

Temp. °F.	Pressure in Cylinder p.s.i.
32	54
41	63
50	73
68	85
59	98
77	112
86	128
95	146
104	170

A new cylinder of gas will be required when the pressure falls to 4 p.s.i. on regulating valve gauge.

The intermittent system may be adopted in which it is desirable to arrange that the smallest possible surface area, apart from the condenser tubes, comes into contact with the chlorinated water. Long pipe lines and culverts impair the efficiency and increase the chlorine consumption. To obtain best results the point of chlorine application should be close to the condenser. Messrs. Wallace and Tiernan use an intermittent system to each condenser, the chlorine solution flowing through a mild steel hard rubber-lined pipe with auto-motor operated valves for injection control. Where the condensers are of varying capacities an auto-controller is included which changes the dose to conform to the flows of circulating water. The cost of the intermittent system is higher than the continuous system but there is an appreciable saving in chlorine for similar maintained condenser efficiency.

Trouble was experienced at one station from a fungus-like growth which reached a remarkable size in a very short time and almost caused complete stoppage of the tubes. It was found that the trouble was bacterial and due to the effluent from a sugar beet factory higher upstream, which worked for some 100 days per annum. Chlorinating plant overcame the trouble.

The escape of chlorine gas at joints, etc., should be avoided as such gas can be dangerous by overcoming attendants. The gas is heavy and always falls so that testing with ammonia in a bottle should always be commenced at the uppermost joint and then work to the lower joints. A leak is readily shown by the giving off of a perceptible vapour.

In flood periods river water carries large quantities of sand and gritty material, and this cleans the condenser tubes. A deposit which has been gradually increasing to such an extent as to impair the heat transfer, thereby reducing the vacuum to a noticeable degree, will be almost cleared by this grit.

The water in a cooling tower system may, after a period, become acid due to the chimney gases blowing down on to the ponds and it is advisable to keep a check on this. The treating of cooling tower water systems with a small amount of copper sulphate has proved effective in ridding the towers of growths of green matter and also maintaining the condenser tubes free from algæ. It has been suggested that the burning of sulphur at the base of a cooling tower will produce mild sulphuric or sulphurous acid and so counteract the alkalinity of make-up water.

Payment for Cooling Water. It is difficult to obtain information on this matter for some river authorities do not charge for water used by power stations, whilst others make a nominal charge. In one case a payment of £100 per annum is made without prejudice and without denial of liability. Another supply authority pays £150 per annum for a period of 25 years in respect of the use of water for condensing purposes for steam engines or turbines of 1,200 h.p. and 1/- per annum for each additional h.p.

The charge for cooling water taken from one canal was 0·002*d.* per kWh. in 1911, but was increased to 0·005*d.* in 1950.

CHAPTER IV

COOLING TOWERS

THE demand for electric power has increased to such an extent that it is now no longer justifiable to restrict large power stations to riverside sites. The trend is to erect stations as near as possible to the centre of gravity of the electrical load by the use of large and highly efficient cooling towers. The function of the tower is to dissipate into the atmosphere the heat contained in circulating water, the heat being extracted by (1) evaporation and (2) convection due to direct contact between the warm water falling through the interior irrigation of the tower and the incoming cold air. Cooling by evaporation is the greatest, and dryness of atmosphere, low atmospheric pressure, high temperature of water and air, and rapid renewal of the air in contact with the water increase the process. Cooling takes place more rapidly in breezy weather when cold air quickly replaces that which has been warmed by contact with the water. The general principle is to distribute by means of troughs the warm water coming from the condensers and transform it into fine spray which will fall from a series of laths or hurdles and cool down by coming into contact with the ascending air. The upward movement of air is brought about by the increase of its temperature and the production of steam lighter than dry air. Part of the tower interior is packed with wooden hurdles, laths and distributing trays for spreading the water to be cooled. The bottom of the tower is open to the atmosphere and a receiving pond is directly below. The circulating water is pumped to a height of from 30 to 40 ft. above pond bottom where it enters the cooling tower stack and is then distributed over trays, laths and hurdles.

The vapours rising from the hot water create a draught of cold air rising from the bottom upwards through the tower. This cold air meets the descending spray of hot water and cools it, the water falling in the form of cold rain into the pond, from which it passes on to the suction culvert and so to the condensers for cooling purposes. A novel use of water from cooling towers is for swimming bath service when the baths are close to the station site. This effects considerable saving in the heating installation of the baths, whilst there is an abundant supply of clean, pure and soft water heated to the correct temperature.

Use may also be made of the height of the tower for providing

the desired static head in connection with fire-fighting equipment of the water sprinkler types. This is accomplished by the inclusion of an elevated " catch " culvert round the inside periphery which is part of the tower construction and normally takes its supply from water condensed on the inside wall above. An overflow pipe led outside the tower will indicate when the culvert is full and by providing pumping equipment it can be maintained full whether the tower is in or out of service.

The cooling process is very complex, and the correct size of cooling tower for any given conditions, although of primary importance, is not easily determined owing to the variable factors to be considered.

The problems to be considered are :—

(1) The heat to be dissipated in the condenser under specified conditions of vacua (usually varying from 28 to 29 in. Hg.) and the inlet and outlet temperatures of the condenser or the amount of steam to be condensed per hour.

(2) The most economic vacuum.

(3) The quantity of cooling water required.

(4) The heat-load for which the towers should be designed.

(5) The average atmospheric conditions for the wet-bulb temperature represents the lowest temperature that can be theoretically attained and tower performance is generally compared with this temperature.

(6) Total heat to be exhausted from the circulating water and the ratio of cooling water to steam condensed.

(7) Design, degree of cooling and situation

When designing a cooling tower station it is essential that the condenser design should be considered side by side with the cooling tower if an economical combination is to be obtained. T. J. Gueritte writes in his paper, " Recent Developments in the Design and Working of Cooling Towers " (Soc. C.E. France), " There is first, direct exchange of heat between the ascending air and the falling drops, through convection. Then there is cooling (and to a much greater degree, generally speaking) produced by the evaporation over the whole surface of the water drops. It is known that evaporation on the convex surface of a drop is so intense that it may take place even in an atmosphere which contains already sufficient dampness to provoke a condensation upon a plane surface. (Sir W. Thompson). Such rapid evaporation induces an important cooling. Further, the steam so produced being lighter than air, this will intensify the draught ; it will be realised therefore that such evaporation is highly important. There is some further cooling by evaporation, on the face of all wet parts of the laths and of the supports of the internal woodwork.

"The evaporation from all these causes is greater when the air coming from the outside is warmer but dryer than when it is cold but already almost saturated, and experiments have proved that a

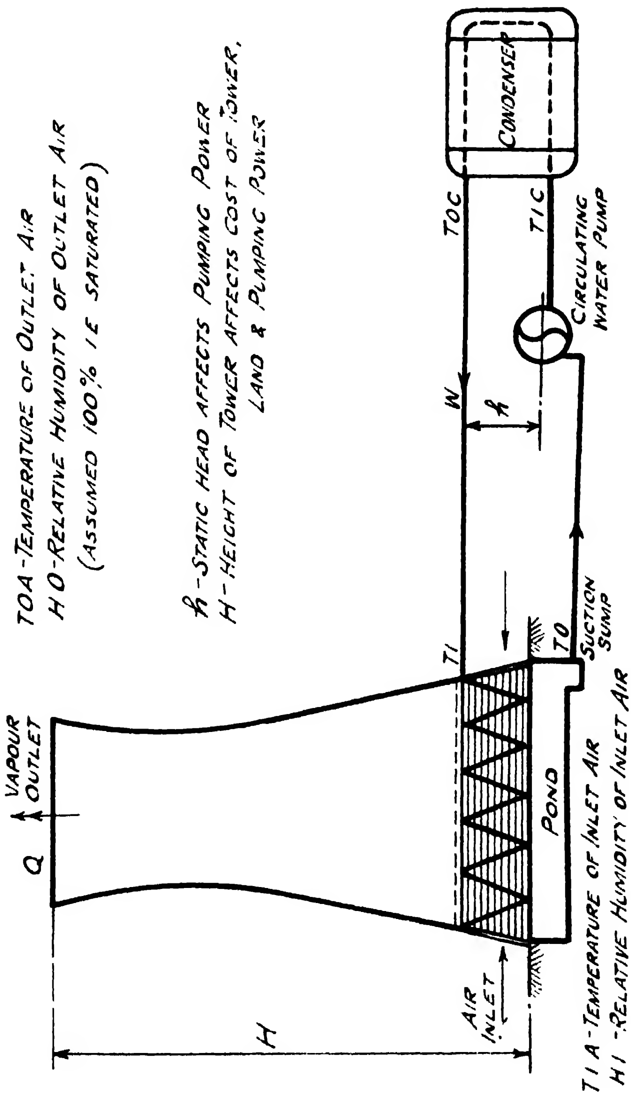


FIG. 87. Cooling Tower System.

cooling tower gives a better cooling when the air is warm but dry than during a cold damp day."

The heat transfer in towers consists of two separate stages, viz.,

latent heat and sensible heat transfer, and may be combined to a very close approximation by considering the difference of the total heat between the free air and saturated air in contact with the water to be the potential causing both types of heat transfer simultaneously.

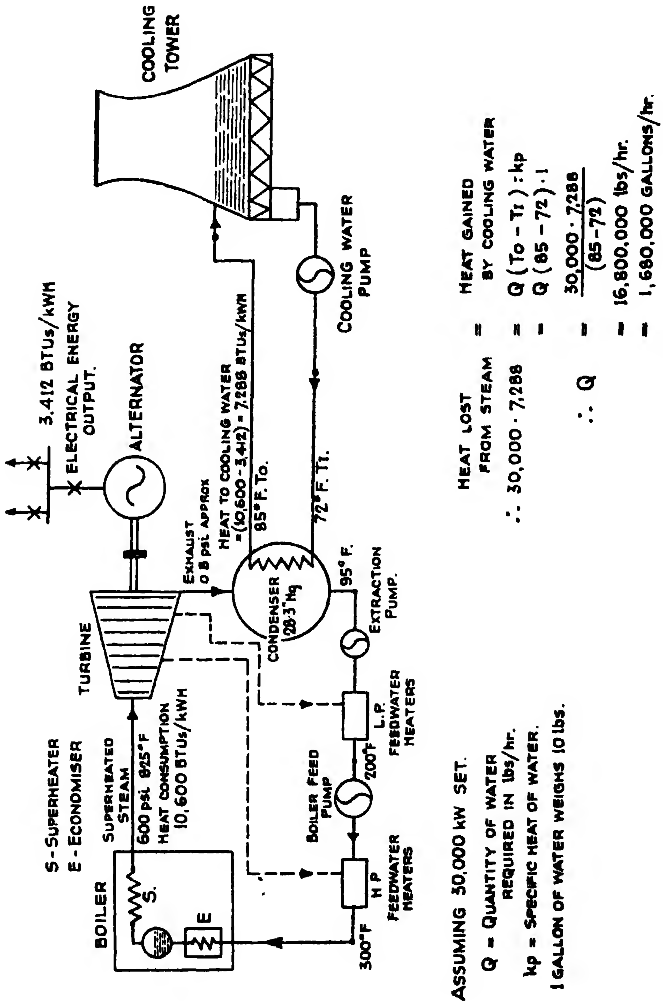


FIG. 88. Typical Cooling Tower System.

Some of the factors which affect the cooling action or exchange of heat are :—

(1) Temperature of the air.
(2) Humidity of the air.
(3) Temperature of the heated water.

(4) Size and height of tower.

(5) Degree of uniformity of the distribution of the descending water or intensity of downpour.

(6) Velocity of air entering tower.

(7) Accessibility of the air to all parts of the cooling stack.

Figs. 87 and 88 indicate the general system.

The upper distribution system shown in Fig. 89, is suitable where the water load is variable. The air meets water under maximum head in trough whatever the water load. Shortage of water may be pronounced at the centre of the tower. The second system is suitable where the water load on tower is steady and it would appear that it can be arranged for the water to be distributed at the outer portions of the stack and so obtain improved cooling. A third system is to have a central chamber inlet with radial distribution troughs carrying the water to the periphery of the stack.

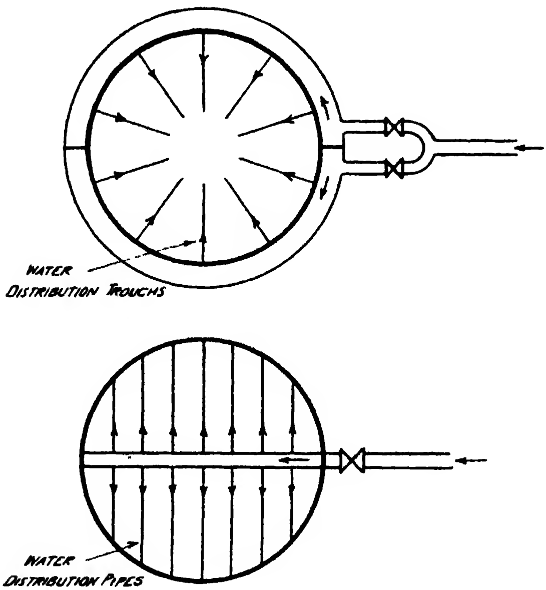


FIG. 89. Cooling Tower Water Distribution Systems.

Theoretical Considerations. In the distribution system (Figs. 90 and 91) the water is broken into very fine rain and the air currents are so disposed that the maximum possible saturation of the air has taken place when leaving the top of the stack on its passage up the chimney of the tower. It is usual to specify the duty of a cooling tower as in the following example :—

"The cooling tower should be capable of reducing 4,000,000 gallons of water per hour from a temperature of 90° F. to a temperature of 78° F. when the temperature of the surrounding atmosphere 4 ft. above ground level is 60° F. dry bulb in the shade and the relative humidity 80 per cent." The performance of a tower may be described as the quantity of water cooled through a specified range, allowance being made for the atmospheric conditions, a lower air temperature usually implying a lower temperature of the re-cooled water. The condenser vacuum would be impaired during foggy weather and experience shows that dry air, even if

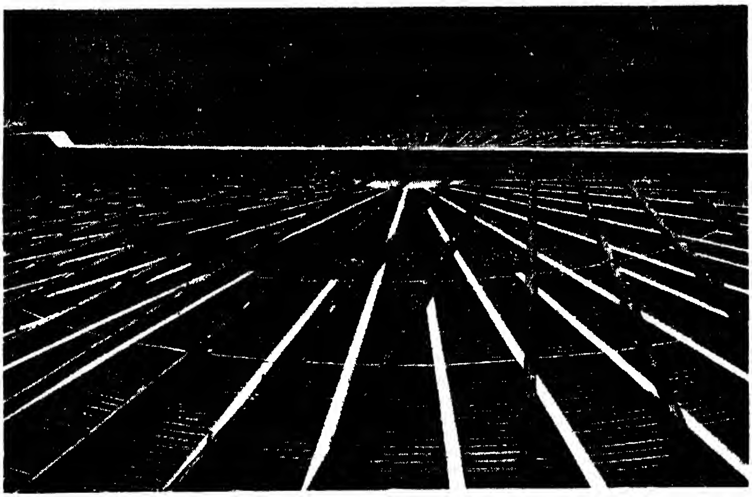


FIG. 90. Distribution Trough and Pipes on Top of Stack. (Davenport Eng. Co. Ltd.)

warmer, cools better and explains why the performance of a tower is better in the morning when the air, although warmer, is generally drier than during the night, when the temperature is low but the atmosphere damp. In certain climates the river water temperature may be higher in the winter than cooling tower water and lower in the summer. The most important consideration is to have the cooling tower correctly designed and of ample size to cool within, say, 10° to 15° of the wet bulb temperature under the worst atmospheric conditions. The figures obtained are usually much higher although in a modern concrete tower the cooling zone near the concrete shell usually re-cools the water to within 4° or 5° of the wet bulb.

The number of degrees from the wet bulb to which the water can be cooled is dependent on the water loading per sq. ft. and the

wet bulb temperature obtaining, and the higher it is, the nearer the re-cooled temperature to the wet bulb. Suitable cooling taken at a wet bulb of 55° F. is 73° F. with an inlet of 87° F. The average wet bulb for this country is 51° F. The purpose of a cooling tower is to extract from the circulating water a quantity of heat equivalent to the amount given to it by the condensation process. The temperatures of the circulating water at the inlet and outlet are therefore variable and will adjust themselves to the running of the turbine plants, atmospheric conditions, etc.

The relative efficiency of the cooling tower used translates itself into the raising or lowering of the temperatures themselves, the difference remaining the same. The efficiency of a tower may be conveniently expressed as :—

$$= \frac{\text{Water Inlet Temp.} - \text{Water Outlet Temp}}{\text{Water Inlet Temp.} - \text{Wet Bulb Temp.}} \times 100\%$$

In a highly efficient cooling tower it may be possible to obtain under given atmospheric conditions a cooling of 18° (from 83° to 65° F.), whereas the use of a poor tower might result in the temperatures fixing themselves, under the same conditions, at 92° inlet and 74° F. outlet.

Performance curves of the Van Iterson (Prof. F. K. Van Iterson—Director of the Dutch State Mines at Heerlen, 1924) type are supplied which show the temperature of the re-cooled water when the volume of the water circulating in the tower is 50 per cent., 75 per cent., 100 per cent. and 125 per cent. of the normal full load rating with a range of cooling varying from 6° to 18° F. at an atmospheric temperature (dry bulb) between 28° F. and 95° F. with a correction curve for determining the temperature of the re-cooled water for various humidities between 50 per cent. and 100 per cent. The curves are drawn on sectional paper and of such scale to enable a reading to $\frac{1}{10}$° F. to be easily observed. A curve is also submitted showing the amount of make-up water in gallons per hour that will be necessary to maintain normal water level in the cooling tower pond when the amount of water circulating, range of cooling and atmospheric conditions are as specified above. The following figures stated as a percentage of normal capacity are common with large towers :—

Make-up water required . . .	1·00 per cent.
Loss due to evaporation . . .	0·99 ,,
Loss due to spray or mist . . .	0·01 ,,

The amount of make-up due to evaporation, spray, etc., may be estimated from $Q_M = (T_I - T_O) \times 0{\cdot}1$ per gallon of water in circulation. This is only approximate but near enough for practical purposes. The quantity of water evaporated by a tower will depend on the amount of heat rejected to the cooling water or in other words the quantity of steam passing to the condensers. The water evaporated is usually about 90 to 95 per cent. of the steam condensed. Further information is given in Vol. II, Chapter X.

The quantity of water evaporated in the towers amounts to approximately 0·5 to 0·6 gallon per unit generated. In passing through the tower the cooling air picks up moisture and consequently there is a continuous removal of circulating water.

The condenser heat transferring surfaces will become coated with deposit or scale if the water in the system is permitted to concentrate indefinitely. The cloud of vapour which is visible at the top of any tower is evidence that water is being lost to the system. The loss is steam—pure distilled water—whilst the make-up is water together with its dissolved solids. Like a boiler, this continual evaporation causes a gradually increasing concentration of dissolved solids which necessitates the cooling-water system being deconcentrated at regular intervals. If such a procedure is not carried out the cooling water becomes saturated with calcium carbonate and scale is deposited.

To keep the permanent hardness of the circulating water within prescribed limits it may be necessary to blow-down the system by varying amounts according to the inherent hardness of the crude make-up water. When the amount of make-up water is limited the use of a softening process to remove the hardness from the water before it enters the system is often useful. Cooling tower timber may be adversely affected by the alkalies introduced to neutralise the acids which would otherwise attack the metals involved.

TABLE 11. *Cooling Tower Tests*

Test No.	Guarantee Figures.	1	2	3
Air temperature, ° F.	69·8	62·6	65·1	64·0
Humidity, per cent.	75	42	37	43
Water flow through tower, g.p.h.	1,980,000	2,900,000	2,250,000	1,670,000
Inlet water, ° F.	100·4	90·3	88·7	86·0
Outlet water, ° F.	82·4	76·6	75·0	70·7

For calculation purposes it is usual to assume that the air passes up the tower at a velocity of about 300 to 450 ft. per minute (velocity at top of stack is about 320) and that it leaves the top of the tower at the temperature of the warm inlet water and saturated with moisture. Air issues from the tower at a temperature of about 70° F. In this way the amount of air required to cool a given quantity of water through a specified difference of temperature can be estimated and from this data the area of the tower necessitated. The relative humidity may be estimated by using wet and dry bulb thermometers. The principle of this hygrometer depends upon the lowering of temperature due to evaporation of water. When the surrounding air is very dry the water evaporates fairly rapidly from the muslin and the bulb is cooled, thus the reading of the wet thermometer will be a few degrees lower than the dry thermometer. When the surrounding air is already damp the evaporation is slower and the cooling of the wet bulb is less pronounced. If the surrounding air is saturated no evaporation takes place and the readings of the thermometers are identical. The difference in the readings of the wet and dry bulb thermometers is a measure of the degree of dampness of the air. As the rate of evaporation depends upon the actual temperature as well as upon the humidity obtaining, the indications of the instrument do not take into consideration all possible circumstances and the dew-point or the humidity has to be deduced from meteorological tables.

Glaishers' Tables or Factors are used in the equation $D = T_d - K (T_d - T_w)$

where D . . temperature of the dew-point.
T_d . . temperature of the dry-bulb thermometer.
T_w . . temperature of the wet-bulb thermometer.
K . . Factor, see table.

TABLE 12. *Dew-point Factors*

Td – ° F.	K.	Td – ° F.	K.	Td – ° F.	K.
40	2·29	48	2·10	56	1·94
42	2·23	50	2·06	58	1·91
44	2·18	52	2·02	60	1·88
46	2·14	54	1·98	62	1·86

$$\text{The relative humidity} = \frac{\text{pressure actually exerted}}{\text{pressure exerted if the air were saturated}}$$

$$\text{or } \frac{\text{pressure in mm. corresponding to temperature } T_d}{\text{pressure in mm. corresponding to temperature D.}}$$

TABLE 13. *Maximum Pressure of Aqueous Vapour*

(The pressure p is given in mm. of mercury)

Temp. ° F.	p	Temp. ° F.	p	Temp. ° F.	p
32	4·58	51·8	9·85	71·6	19·84
33·8	4·92	53·6	10·52	73·4	21·09
35·6	5·29	55·4	11·24	75·2	22·40
37·4	5·68	57·2	11·99	77·0	23·78
39·2	6·10	59·0	12·79	78·8	25·24
41·0	6·54	60·8	13·64	80·6	26·77
42·8	7·01	62·6	14·54	82·4	28·38
44·6	7·51	64·4	15·49	84·2	30·08
46·4	8·04	66·2	16·49	86	31·86
48·2	8·61	68·0	17·55	104	55·40
50·0	9·29	69·8	18·66	122	92·60

The height of the inlet to the tower plays an important part in the tower duty, the higher the inlet the greater the capacity of the tower, although the pumping and tower costs will be greater but there is a saving in land. The quantities of water to be dealt with by a tower may be estimated from the temperature drops through the condensers or alternatively by using a pitot tube which by measurement is within 2 per cent.

In one station the cooling towers were designed for a vacuum of 28 in. Hg. with average conditions of 60° F. (dry bulb temperature) and 70 per cent. humidity which necessitated 31,500 gallons of cooling water per minute for a 50 MW set operating at maximum rating under feed-heating conditions. At an economic rating of 40 MW the vacuum obtainable would approach 28·25 in. Hg.

In another station the towers were designed for a vacuum of 28 in. Hg. with average atmospheric conditions of 60° F. dry bulb in the shade and relative humidity of 80 per cent. which necessitated a flow of 46,400 gallons of cooling water per minute for a 50 MW set operating at maximum rating under feed-heating conditions.

An outlet temperature of 80° F. was assumed in the second example.

At a rating of 30 MW with feed-heating the vacuum obtainable is approximately 28·4 in. Hg. It may be mentioned that under atmospheric conditions of, say, 60° F. dry bulb temperature, cooling towers for a vacuum of 29 in. Hg would be impracticable.

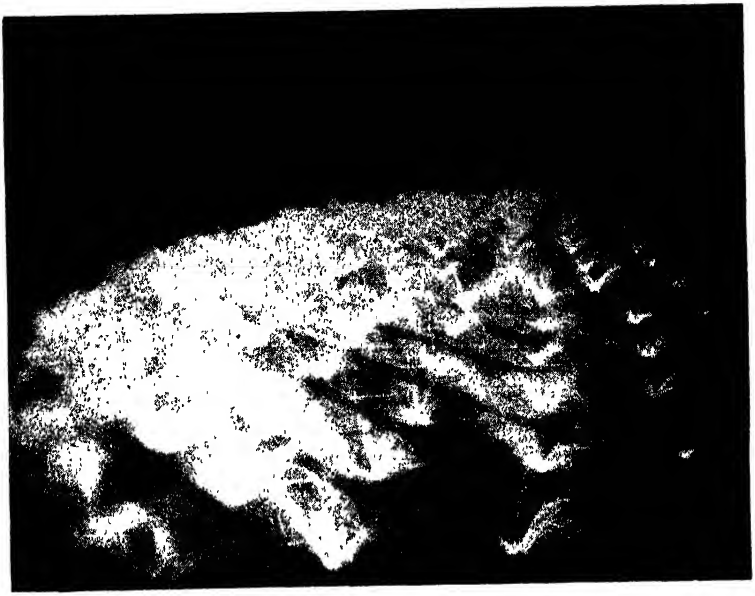


FIG. 91. Sprays discharging from Distributing Pipes.

TABLE 14. *Cooling Tower Tests*

Tower	1	2	3
Circulating water to tower, gallons per hour	2,736,900	3,480,800	1,550,000
Mean temperature of water to tower, °F.	91·40	90·84	83·0
Ditto from tower, °F.	77·66	77·22	70·8
Wet bulb temperature, °F.	59·6	40·7	41·0
Dry bulb temperature, °F.	65·1	42·7	43·7
Calculated humidity, per cent.	72·2	84·5	88·0

Types. Cooling towers for power station service are of the following types : (1) Timber. (2) Ferro-concrete, the latter being used on all large capacity stations. (3) Multi-deck concrete towers,

(4) Special concrete water tower type which is claimed to be highly efficient, the height being considerably less than the hyperbolic type for the same output. (5) Forced draught towers. (6) Induced draught towers. Timber is used for small towers, but has a number of disadvantages, some of which are :—

(1) Tendency to rot and deteriorate due to exposure to wind and water under alternate dry and damp conditions.

(2) Maintenance charges are relatively high and the life of a tower may be comparatively short. On the other hand, many towers are still giving good service after 25 to 35 years with reasonable maintenance charges. The water capacity per sq. ft. of ground area is between 50 to 70 gallons per hour.

(3) Greater risk of fire, particularly during construction periods.

(4) Where a large number of small towers are required the efficiency of some of the towers may be impaired due to their positions.

(5) The design, construction and layout, speaking generally, does not facilitate air circulation.

The inlet water enters the tower at a height varying from 18 to 20 ft. above sill level although 27 to 30 in. is common on concrete towers.

Ferro-concrete towers are now universally adopted for all large stations. Individual towers capable of dealing with 5,000,000 gallons of cooling water per hour have been constructed and proved satisfactory.

The advantages of this type are :—

(1) Larger capacity towers are possible, thereby bringing about a reduction in area of land required. On irregular shaped sites it is possible that equal capacity can be obtained with wood towers.

(2) Improved draught and air circulation are obtained due to increased height and better shape, resulting in higher efficiency.

(3) Maintenance charges are low.

(4) Fire risks are minimised.

(5) Cost of pipework and valves is reduced.

(6) Withstands bomb blast.

(7) Higher water rate per sq. ft.—100 gallons per hour and over.

(8) A wide base leads to stability under wind pressure, double curvature resists buckling and shearing stresses in the structure due to its own weight are suppressed.

The hyperbolic natural draught towers common in European practice are not feasible in U.S.A. because the summer time dry-bulb temperatures is so much higher.

A disadvantage of ferro-concrete cooling towers is the high initial cost.

Multi-deck towers have been suggested with a view to taking

advantage of the improved performance in the annular zone and so obtaining a lower outlet temperature from the tower. Re-cooling to within 5° of the wet bulb is possible near the concrete shell. In both concrete and timber towers the filling material occupies between 4 to 5 per cent. of the void in which it is installed, whilst about 4 to 5 sq. ft of stack surface area is required per B.Th.U. per second dissipated from cooling water. The heat to be absorbed by

air inflowing up tower, $H_T = W \times 10(T_{OC} - T_{IC})$
$= 10W(T_I - T_O)$ B.Th.U.s per hr.

where W = circulating or cooling water g.p.h.

Total air required per hr. lb. $= \dfrac{H_T}{H_N}$.

H_N = nett heat carried away from tower per lb. of air flowing through it. (Difference between inlet and outlet air conditions.)

Weight of circulating water

evaporated per hour per lb. $= \dfrac{H_T}{H_N} . W_I$

W_I = increase in weight of vapour per lb. of air flowing through tower.

$$Q = \frac{H_T}{H_N} . \frac{W_I}{10} \text{ gallons per hour.}$$

Take for example cooling towers having a capacity of 5 m.g.p.h. and assume a rise through the condenser of 15°.

3–30 MW turbo-alternators, 600 p.s.i, 850° F.

Heat consumption	10,500	B.Th.Us. per kWh.		(M.C.R.)
Energy to busbars	3,412	,,	,,	,,
Heat to cooling water	7,288	,,	,,	,,

say, 7,300 B.Th.Us.

$$P . H = Q(T_I - T_O)$$
$$P . 7{,}300 = 5 . 10^6 . 10 . 15$$

P = kW
1 gall. water = 10 lbs.

$$\therefore P = \frac{5 . 10^7 . 15.}{7{,}300}$$
$$= 102{,}000 \text{ kW.}$$

As check 950/1,000 B.Th.U./lb. of steam rejected to cooling water.

Steam condensed /kWh = 7·3 lb.
Heat to cooling water = 7·3 × 1,000
= 7,300 approx.

With wooden towers 75° F. re-cooled circulating water temperature is possible giving a vacuum of 28 in. Hg. whereas with concrete towers 70° F. and a vacuum of 28·5 in. Hg. can be obtained. An average winter figure of 28·75 in. Hg.—66° F. re-cooled water temperature is usual.

Some wooden towers have been fitted with lightning points and conductors but there appears to be little need for them except where the towers are likely to be out of service for considerable periods. Cases are on record where dry towers have been damaged by lightning.

Ferro-concrete Towers. The hyperbolic ferro-concrete tower offers little or no impedance to air flow, and when arranged in groups there is no trouble due to eddies or local depressions. The construction is good from a structural point of view and also provides and regulates adequate air draught as the air streams are directed towards the vertical axis of the tower. The tower consists of a smooth reinforced concrete shell which, depending on the capacity, may extend some 260 ft. above the pond level. This construction offers greater resistance to wind pressure, eliminates shearing stresses and internal bracings, thus avoiding the formation of eddies. Further, the lightness of the shell saves foundation work, and ground loadings of 1 ton per square foot and under are possible. The tower pond, outlet staircases and gangways are constructed as one unit.

The shell (1 : 2 : 4/$\frac{3}{4}$ mix and not less than $\frac{3}{16}$") is supported on specially arranged reinforced concrete columns designed to offer a minimum resistance to air flow through the chimney. These columns take the shear.

In the vicinity of private property towers should be so designed that the emission of moisture in the form of spray from the chimney is reduced to an absolute minimum to avoid nuisance. Complaints have been recorded from householders that a nuisance was caused due to condensation of moisture from nearby cooling towers. At times the housetops were swimming with water and heavy froth, the descent of the vapour varying according to the humidity of the atmosphere. During winter months trouble may be experienced from ice building up around the tower and ice deposits on nearby roads may necessitate salting or ashing. It is sometimes necessary to remove some of the stack timber to facilitate the passage of air and so reduce the precipitation outside the top of the tower.

With the hyperbolic tower the widening of the top of the chimney permits of condensation taking place within the tower of a certain

amount of the water evaporated at lower levels. The velocity of the rising air within the chimney is diminished before exit thereby avoiding eddies around the top. A further method of trying to minimise emission of spray is the inclusion of a number of openings in the upper portion of the chimney. It is claimed that the suction caused by the draught induces a quantity of cold exterior air through the openings and provokes condensation of the interior steam rising in the chimney. The effect of such openings depends to an extent on the wind and some tower designers do not recommend them. One maker fits inclined cement pipes with back-valves into the top part of the tower which admit air to the rising vapour, thus causing precipitation within the tower, at the same time preventing escape of vapour through the pipes.

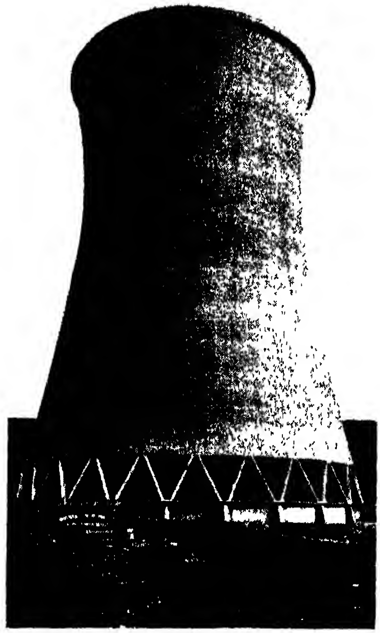


FIG. 92. Reinforced Concrete Cooling Tower of 1½ million g.p.h. capacity. (The Davenport Engineering Co. Ltd.)

Originally it was thought that precipitation was caused mainly by condensation from the moisture-laden air discharged from the top of the tower. The precipitation is usually the result, not of condensation, but of droplets of water carried over by the air stream leaving the tower. An eliminator consisting of a louvred wooden screen and placed some 10 ft. above the internal stack appears to be effective in eliminating the droplets carried upwards. This screen or eliminator is fitted horizontally to cover the entire cross-section of the tower. Tests show that an efficiency of droplet removal of between 90–95 per cent. is possible.

Near the base the chimney spreads out, all the water falling into the pond without the use of louvres which obstruct the ingress of air by decreasing the pressure drop across the tower. Large towers can be arranged so that it is possible to work either half of the cooling stack alone. The towers have two inlet conduits which serve a number of water inlets arranged to give the most efficient distri-

bution of water over the whole area of the cooling stack. In some cases a double annular conduit formed with the shell is used and is designed to maintain the same velocity of water in both the interior and exterior conduits. This is obtained by making the cross-section of the exterior conduit twice that of the interior conduit as the former discharges in either direction into the latter. The water is taken to the tower by a pipe, or reinforced concrete culvert, which divides, each half running to its respective conduit. Spun concrete pipes are more costly than sections cast in situ. The discharge water culvert can be supported on reinforced concrete columns and run directly above the suction culvert. The discharge culvert may be taken straight into the tower from which 4 in. bore asbestos cement pipes distribute the water across the stack (Fig. 90). A manhole is provided to give access to the culvert inside the tower. With this arrangement the tower cannot be operated in halves. Each pipe can have a valve to enable half of the tower to be isolated for inspection and maintenance purposes. Valves are arranged for electrical and manual operation. The internal timber cooling stack is supported independently of the shell and is constructed in such a manner that in the event of any movement the weight or pressure is not thrown on the shell structure. The Film Cooling Tower Ltd. have laths inclined in the direction of their length supported between stack posts by rails, the water flowing along these laths from top to bottom. Concrete laths have been used and compare favourably with wood but are more costly. The rectangular laths are larger than the usual triangular wood laths but the surface area is greater.

The timber work such as posts, bearers, louvres, trough frames, etc., are of pine, and the water-distributing trough of red cedar or red deal; concrete is also used. Nails, if used, should be galvanised or of copper.

Cleaning of the timber stacks depends to a large extent on the water used and it is found that when a tower is out of service any algæ growth dries out and dies, forming a powder deposit which is washed down when the tower is again put in service. The whole of the timber (except that over which the water flows) is creosoted under pressure before leaving the works. The decay of the wooden slats has sometimes been attributed to "soft rot." Certain research work has been carried out with the idea of using hardwoods, but some, on being leached, extruded a sticky gum which was undesirable in the cooling water.

Each tower stands on its own pond, and can be isolated for

cleaning by means of penstocks from adjacent ponds and the return water culvert for cleaning.

The pond should have adequate area and depth and may be

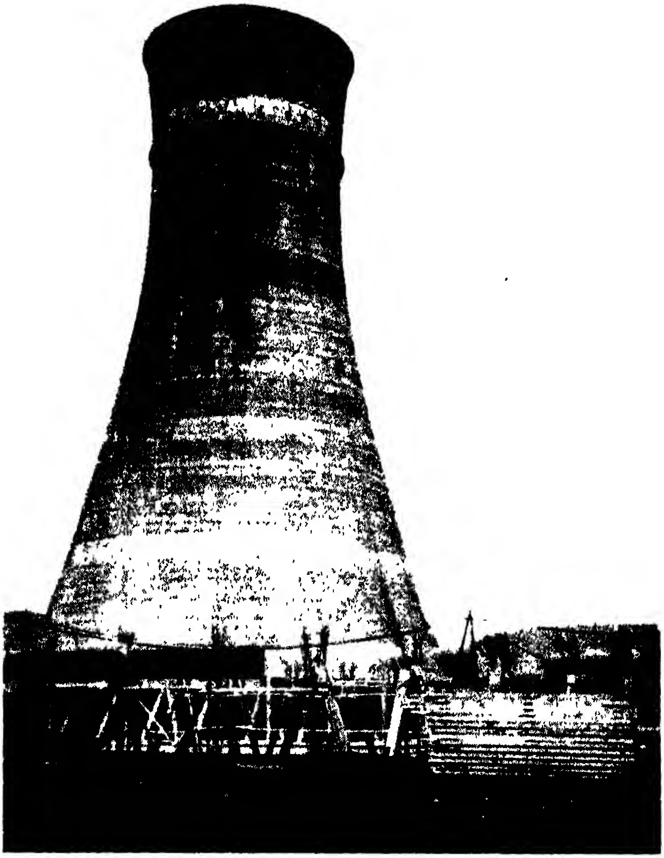


FIG. 93. Reinforced Concrete Cooling Tower of 3,500,000 gallons per hour capacity. A second tower is in course of construction. Blackburn Meadows Power Station, Sheffield. (Mitchell Eng. Ltd. and Mouchel & Partners.)

divided so that one-half of the tower may be put out of service. Where two suction culverts are installed for a group of towers it is advisable to provide openings with temporary concrete fillings (or dam boards) so that adjoining ponds may be interconnected to

facilitate culvert cleaning. Access should be provided to the ponds and cat ladders at opposite sides are sufficient. The reinforced concrete foundations around which the ponds are built, and are integral with, should be arranged to cause minimum obstruction to the flow of water to the culverts. The surrounding ground area up to within 30 ft. from the base of the tower may be paved with concrete. The paving should have a fall for drainage to collect water blown out by the wind.

Hand-railing is necessary to prevent attendants sliding off the surround into the pond and a concrete curb can be carried around the pond wall. Tower ponds usually require cleaning annually, the mud and sand deposit over this period varying from 4 to 9 in. in depth and drainage facilities should be provided. The ponds may slope away from the central point and sludge channels carry the silt to a sump. For cleaning purposes a double fire hydrant can be provided on the dividing wall and a standard hose is supplied from the circulating water system.

Where sewage effluent is used for cooling-water make-up, the water in the annular discharge conduits round the towers is frequently found to give off a quantity of froth. Wind blows the froth on to the surrounding ground and this in a short time becomes a nuisance. The valves, operating gears, platforms, stairways, etc., become coated with a slimy film, and this increases maintenance. The ground area in the vicinity of the towers should be paved with concrete, provision being made to wash down by hose.

The inside and outside faces of the shell have a reasonably smooth finish and the former may be given two coats of bituminous paint. Some ferro-concrete towers show damp patches on the outside face which appear to be the result of leakage through percolation. These may be caused by "rain" from the top which gathers and shows itself at any part of the shell where there are irregularities due to shutter marks, etc. If this dampness is due to percolation through porous parts of the concrete it is found that they seal themselves in due course, and do not appear to have any detrimental effect on the steel reinforcement. The question of "right of light" must also be considered when deciding on tower positions.

The leading particulars of one 1,650,000 g.p.h. tower are :—

Water loading per sq. ft. of ground area	110 g.p.h.
Internal base diameter	128 ft.
Overall base diameter of pond	138 ft.
Height of chimney from pond bottom	191 ft.
Height of stack from pond bottom	25 ft.

Depth of pond	6 ft.
External diameter of tower at top	92 ft.
Area of timber surface	280,000 sq. ft.
Inlet pipe	36 in.
Outlet pipe	42 in.

Cooling range 87° F. to 73° F. at 55° F. wet bulb.

The following data relates to towers having a cooling capacity of approximately 3,000,000 to 4,000,000 gallons of water per hour or thereabouts. :—

External diameter of tower at pond floor level	155 to 160 ft.
External diameter of tower at throat	70 to 75 ft.
External diameter of tower at top	78 to 90 ft.
Height of tower from pond water level	250 to 260 ft.
Depth of water in pond	4·5 to 7·5 ft.
Total weight of tower and foundations	4,000 to 4,700 tons
Total weight of steel reinforcement	500 to 600 tons
Factor of safety -shell	4 to 5
,, ,, - columns	4 to 5
Wind pressure	50 lb. per square foot
Maximum intensity of load on ground	1 ton per square foot
Dimensions of pond	180 × 180 ft.
Distance between top of cooling stack and top of tower	220 to 240 ft.
Depth of cooling stack to normal pond water level.	20 to 25 ft.
Height of water level in distribution troughs above pond water level	24 to 25 ft.
Type of distribution	Troughs and nozzles or upward jets with self-adjusting sprayers.
Span of distributing troughs or pipes	2 to 10 ft.
Number of sprayers	1,800 to 2,900
Material of sprayers	Brass or stoneware
Make-up water required per cent. of normal capacity	0·9 to 1·0
Loss due to evaporation per cent. of normal capacity	0·89 to 0·95
Loss due to spray or mist per cent. of normal capacity	0·01 to 0·05

Concrete of the "Ordinary Grade" mix reference No. 111 is used for reinforced concrete, and a 1 : 3 : 6 mix for mass concrete. The allowable stresses are as for "Ordinary Concrete Mix IV." The shell of a tower of this capacity can be constructed at the rate of from 2 ft. 6 in. to 3 ft. per normal working day. Shuttering is removed after one day.

Forced Draught Towers. These towers consist of cells, each cell having a propellor type motor-driven fan. Forced draught cooling was installed many years ago in this country, but the large towers

now required almost prohibit its adoption. The power requirements are high and repairs and maintenance charges are higher in respect of fans, etc. A ten-cell tower having a cooling water capacity of 1,200,000 g.p.h. of water from 97·5° F. to 85° F. with an entering wet bulb temperature of 70° F. measured at the inlets will require a 25 h.p. motor propeller fan for each cell.

Induced Draught Towers. Claims are made that this design has the advantages of lower first cost, requires less space, capable of cooling through a wide range, and using only 50 per cent. of the water throughput. This latter point leads to reduction in first cost of pumps and water pipes and lower power consumption. The construction is similar to the venturi-tube type towers and at the narrowest point of the throat is a horizontal fan rotating at 90 r.p.m. and driven by a vertical shaft from gearing located at the base of the tower. As the speed of the fan is controlled by the temperature of the cold water, power is not wasted when the ambient temperature falls. A natural draught tower for 30 MW uses about 570 kW. in pumping compared with 310 kW. for induced draught. To the latter must be added 280 kW. for the fan drive. The weather conditions may be such that the fan may only be needed for 40 to 70 per cent. the time the tower is operating, so that 170 kW. may be taken as the mean fan load. Higher carry-over is experienced and make-up water may present a problem at times of water shortage. Figures given comparing costs of natural draught and fan-cooling towers in Germany (1943) are as follows :—

	Cost
Normal steel and wood natural draught towers	£31,000
Equivalent fan cooling	£25,150
Strengthened steel and wood towers	£52,300
Equivalent for fan cooling	£33,450
Concrete strengthened fan cooling towers	£38,900

All are assumed to have a capacity of 180,000,000 B.Th.U. per hour. The throughput of the natural draught tower is 1,760,000 g.p.h. compared with 880,000 g.p.h. with induced draught, and the temperature ranges are 88°–77° F. for the former and 90°–68° F. for the latter.

For further data see Information Bulletin, No. EG(51)8, of the National Coal Board (Production Dept.), 1951.

Combined Natural and Forced Draught Towers. In one small plant where water for use in connection with the various processes is taken from the town main, economy is effected by using a combined natural and forced draught hyperbolic reinforced concrete cooling

tower. It is capable of cooling some 180,000 gallons of water per hour from 105° to 80° F. when operating in an ambient wet-bulb temperature of 60° F. A 32-ft. diameter stainless steel impeller is located in the throat and is driven through a horizontal shaft and reduction gear box. A motor is fitted at each side of the gear box and they are capable of giving full load and two-thirds load, respectively; thus where climatic conditions are favourable, the smaller motor can be used with consequent savings in power. To reduce carry-over to a minimum, a timber eliminator screen of the pear-shaped lath type is included.

CHAPTER V

COAL-HANDLING PLANT

When designing a station careful thought should be given to the coal-handling plant, particularly the design and layout of the individual units. The design should be sound and simple, having a minimum number of units of robust construction with a view to reducing maintenance and running charges to the lowest possible figure consistent with that all important factor—reliability. In many cases this plant does not receive the attention warranted, with the result that as a station ages a large amount of trouble is experienced.

The station designer should be wary of cheap plants, for more often than not they are only a direct result of low overhead and engineering charges and generally at the expense of experience, design and first-class manufacture. To safeguard the purchaser a clause may be inserted in the specification to the effect that similar plant to that put forward must have been in commercial service for a given period of time. Although this is an advisable precaution, it is not always policy to adhere to a stereotyped design and layout. As far as the mechanical handling of coal is concerned much remains to be done in development and design. The aim should be to eliminate handling units wherever possible, thus reducing the operating and maintenance charges. Also the running equipment such as crushers, screens, magnetic pulleys, weighers, hoists, conveyor drives, etc., should be centralised to reduce general charges and facilitate inspection and maintenance. Heavy wear in mechanical parts and chute linings can be reduced by using lower grades of abrasion resisting alloys. High strength steels are common on heavy elevator and conveyor shafts when used in combination with manganese steel sprocket wheels. Monel is an alloy of nickel and copper which develops a strength equal to that of steel, together with high resistance to most corrosive conditions. Monel screws and bolts have proved useful in place of steel for many purposes. Transparent plastics will also supersede glass in many applications.

The power station designer can materially assist in problems of this nature by placing his needs before the manufacturer, and by mutual co-operation it should be possible to evolve an equipment which will give satisfaction.

With the rapid increase in power-station plant capacity, together

with the fact that the cost of coal may be of the order of 66 per cent. of the total station operating cost, it is evident that the handling of the coal should be carried out as expeditiously and economically as possible. The site conditions will in many cases determine the type of plant it is possible to employ, whilst the question of storage must be borne in mind.

Whatever methods of handling are adopted they should be sound, simple and require a minimum of operatives. The outputs of power stations have grown to such an extent that it is impossible to handle the required amount of coal by manual methods within the time available.

Further, it must be remembered that restrictions are likely to be placed upon railway, canal, river and sea transport during war or other emergency conditions. Also, the demurrage charges incurred upon wagons and ships delayed in sidings and wharfs together with the inevitable spasmodic supply of wagons make it necessary to unload a considerably greater number of wagons per day. Riverside coaling may be affected by the speed of current and tidal range which in turn affects wharf space. To cater for such eventualities the coal-handling plant should be designed to deal with a much greater rate per hour than that required under normal operation.

Electrical appliances have all the advantages required of modern handling equipment namely: reliability, flexibility, comparative cheapness in cost of supply mains, high residual value and economic power consumption which make the choice of electric drive with certain exceptions almost universal. The coal required for a large station can be estimated as follows :—

300 MW capacity.
Load factor 50 per cent.
Assuming 1·2 lb. of coal per unit generated, coal required per annum

$$= \frac{300{,}000 \times 1{\cdot}2 \times 50 \times 8{,}760}{100 \times 2{,}240}$$

$$= 710{,}000 \text{ tons.}$$

The handling plant should be such as to avoid double handling, *e.g.*, it must not be necessary to deliver all coal received into the store before it can be taken into the boiler house bunkers. Once the coal store is filled it should be held as reserve until an emergency arises and new supplies should go directly into the boiler house bunkers for immediate consumption.

The trend towards total enclosure of working parts is a good one. It provides for the exclusion of abrasive dusts and corrosive vapours,

greater protection from danger to the operatives, since it is not an afterthought, greater precision in construction and functioning of working parts, and usually the application of more efficient means of lubrication. These remarks also apply to ash handling plant. The designer can help the maintenance staff by giving some thought to the carrying out of future repairs and the conditions under which they need to be done. Means of access is of prime importance ; there should be provided a platform of sufficient size and suitably positioned from which the work can be done without the need for over-reaching or standing on handrails.

Transport. The methods of transporting coal to power stations depends primarily on the location of the station, but will be one or more of the following : Sea, river, rail or road-borne coal. The ideal site would permit of any being used should the need arise, but in general, rail and sea transport are the most common, the latter being much cheaper. Access for sea-borne coal is therefore a most valuable asset to a power-station site.

Stations should be placed near the coalfields to reduce the transport charges. It sometimes happens that the cost of fuel is much less at sites further from the coalfields where sea-borne coal is available than on sites in close proximity to the coalfields where rail transport is used. Other factors to be kept in mind when considering these problems are the suitability and prices of the varying classes of coal together with the legislation that may obtain regarding the control of production and selling of coal.

Where rail transport is used the necessary sidings should be brought as close as possible to the boiler houses. The sidings are connected to the railway companies' main lines so that wagons can be shunted to the appropriate unloading positions on the site. It is a decided advantage to have separate incoming and outgoing tracks to the main lines thereby enabling the wagons to be discharged and taken from the site with a minimum of shunting operations. Adequate sidings should be provided on the site so that a reasonable number of full and empty wagons can be marshalled to deal with normal and abnormal working conditions.

The sidings for one 250 MW station were as follows :—

Incoming wagons (full) 300 (3,000 tons approximate).
Outgoing wagons (empty) 350 (3,500 tons approximate).
Average daily consumption, 2,200 tons.

In a number of stations sidings providing for three days' capacity have been installed.

The movement of wagons within the sidings may be carried out by means of capstans and bollards along the sidings. Sea-borne coal necessitates the use of sea-going colliers to bring the coal direct to the station unloading wharf where it is discharged by cranes into hoppers (Fig. 94), placed above belt conveyors, whence it is taken either to the boiler-house bunkers or alternatively to storage. Electricity undertakings now own and operate their own colliers, and

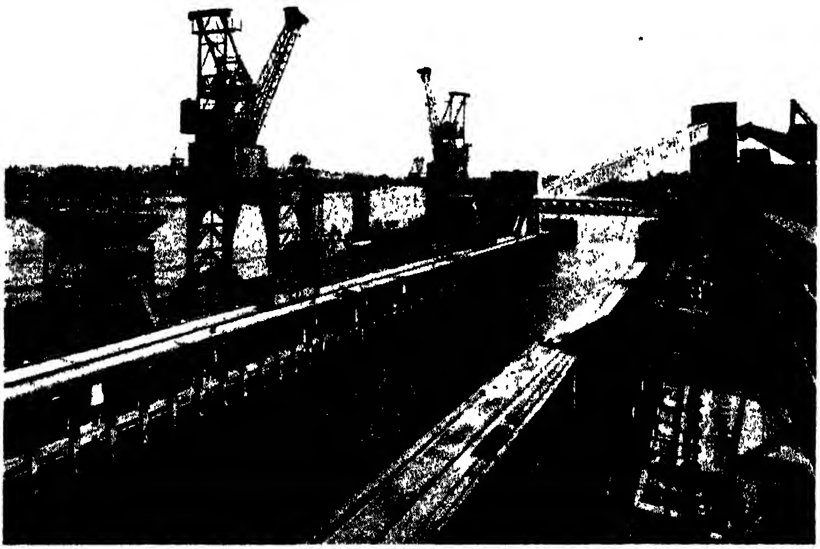


FIG. 94. Jetty, Coaling Cranes and Conveyors, Battersea Power Station.

where colliers are unable to reach the station, barges may be used. The cargo holds of the colliers should be designed with sloping wing ballast tanks so that the coal flows by gravity to the discharging grabs thus expediting handling of the coal. Where vessels have to negotiate the arches of low span bridges the masts and funnels should be arranged to be lowered and deck houses and superstructures should be of navigable limits. In view of the conditions under which vessels may have to operate, careful attention is necessary in their design and particular care is called for in connection with draft, trim and clearances in each of the load and ballast conditions.

In large stations road-borne coal is rarely resorted to except in emergency conditions, although road transport may prove cheaper and more reliable than rail if the coal can be brought direct from pit to station receiving hoppers and the distance is not too far. A well-constructed road giving access to the coal-receiving plant would probably meet all requirements. Attention should be given to the covering of coals by tarpaulins during transit and to the design and condition of vehicles. Trucks should have adequate drainage arrangements and barges should be watertight. Coal may be unloaded from barges by means of a suction plant in which the suction is created by a reciprocating vacuum pump. The majority of the coal-handling plants are similar, whatever methods of transport are used, but some special equipment will almost invariably be required for each method.

Methods of Handling. No matter how the coal is brought to the site it still has to be taken to the boiler stokers or the coal-preparation plant in the case of pulverised fuel boilers. The ideal arrangement would be of course for the wagons to run directly above the boilers and discharge into overhead bunkers. This has been possible on rare occasions due to the site conditions lending themselves admirably to this layout. Should underground stations come into use then the ideal arrangement could be adopted, but other sections of plant would suffer in consequence. A reasonable amount of coal should always be held in readiness to serve the stokers or milling plant, and the general practice is to provide overhead storage bunkers in the boiler houses. The coal delivered to site has therefore to be weighed, emptied from wagons or ships, then lifted or discharged into the overhead bunkers in the boiler houses. To carry out these operations various types of equipment have been used, some of which are: skip hoists, bucket elevators, belt conveyors and telphers, together with trucks, tipplers, cranes, wagon hoists, drag-line buckets and winches. The first mentioned are usually cheaper, whilst labour and maintenance charges are low. It will be observed that the methods outlined are defined by the manner in which the coal is raised to the overhead bunkers as the majority of the auxiliary plant is common to each method of handling. The method adopted will to some extent depend upon the site, but, other things being equal, careful consideration should be given to all possible methods so that the best plant for the specific purpose may be obtained. The following particulars are typical :—

Type of C.H. Plant	Power Consumption kWh/ton	Wt. of steel tons	Total Cost £
Gravity bucket conveyor	0·22	45	5,000
Belt conveyor	0·15	35	3,600
Bucket elevator	0·20	25	2,900
Skip hoist	0·20	20	2,500 includes auto-electric equipment

To provide against failures of coal supply in the event of labour troubles, unfavourable weather conditions, accidents, warfare, etc., adequate coal reserves should be kept on or near the station site. For large stations it is considered desirable to have coal reserves on site of 50,000 to 150,000 tons. The storing of coal necessitates the provision of special handling plant apart from other factors which are considered under a separate section.

The storage handling plant varies considerably, a great deal depending upon the nature of site and, in particular, the shape.

Some of the usual types of equipment are :—

(*a*) Travelling bridge complete with belt conveyors and reclaiming cranes arranged to span the coal storage area and permitting of the coal being deposited at any part of the coal store or reclaimed therefrom as desired for delivery into the boiler-house bunkers.

(*b*) Telpher equipments arranged to travel over the storage area and deposit or reclaim coal as required.

(*c*) A system of belt conveyors with travelling-belt distributors for depositing the coal and steam jib-cranes on rails for reclaiming the coal and dropping it into travelling receiving hoppers.

(*d*) Drag scraper which deposits and reclaims and is operated in association with conveyors and skip hoists.

Other types are to be found in practice differing only in items of plant but having the same underlying principles.

The coal-handling plant should therefore be designed so that it is possible to handle coal from railway wagons, ships or road vehicles to the boiler bunkers ; also from these to the reserve store or from the latter to the bunkers (Fig. 95).

In one station the plant includes a travelling unloader for discharging river-borne coal, a tippler hoist for rail-borne coal, a drag scraper storing and reclaiming equipment, weighing machines

and a belt conveyor system interconnecting the component parts of the plant. The electrically operated riverside unloader discharges the coal into a hopper-type weighing machine, fitted with totalising gear to record automatically the weight of coal passing to the succeeding belt conveyors. The wagons containing rail-borne coal are emptied by an electric tippler, the wagon and its contents being weighed in the process. Wind screening and dust extraction plant is provided at the points of discharge from the barge and wagon unloaders. Coal to be stored is conveyed by belt to a central pile

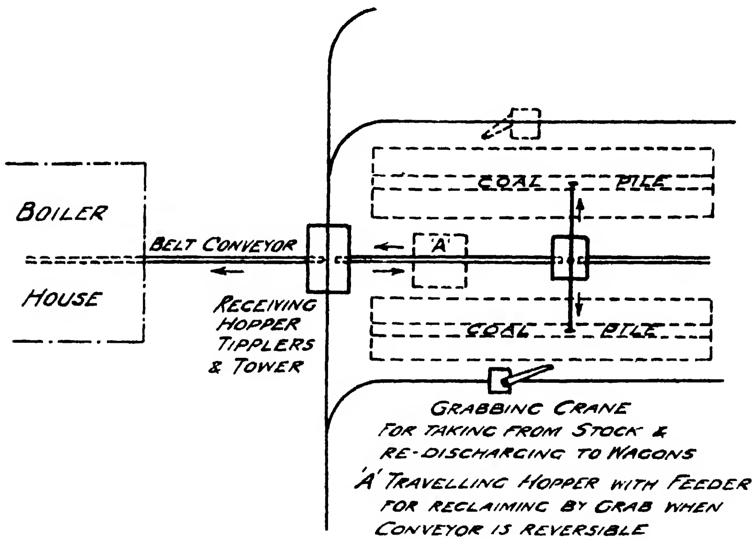


FIG 95. Coal-Handling Plant.

from whence a drag scraper distributes it over the storage area. When the store is to be used it is drawn by drag scraper to a loading hopper and carried thence by the belt system to the boiler house bunkers. A belt weighing machine on the conveyor elevating the coal to the bunkers records the weight of all coal delivered, either from the unloading plant or from the store.

To eliminiate nuisance attention must be paid to enclosure of coal-handling plant. The coal tipplers may be enclosed in a separate dust-tight building having motor-operated sliding doors from which fans can extract the dust-laden air and discharge it through separators. A similar method can be applied to coal breakers, conveyors and bunkers. Suction plants have also been employed with satisfactory results.

Motor-operated Wagon Tipplers. Are usually of the rotary and side discharging types, the choice depending on the layout of the filler-pit or receiving hopper. When clinging or wet and small coal is being handled, inversion of the wagon and the consequent movement results in complete discharge. Other types are used to serve special conditions. Tipplers are standardised in design and construction to suit the types of wagons now in use, although special designs are occasionally adopted. One or two tipplers are provided for each boiler house, and in some installations means of interconnection are included in case of breakdown. Bottom discharge wagons empty on to a grid in the receiving hopper, then through feeders to the conveyors.

Tipplers are designed to handle any standard railway wagon from 8 to 20 tons capacity, the shape and dimensions of which comply with the relevant Railway Clearing House Specifications. They are capable of handling and tippling the requisite number of wagons per hour this time including weighing and recording the gross and tare loads.

The loaded wagon is run on to the rocking table in a position ready for tippling, is weighed, and then by means of an electrically driven winch turned to its discharging position. The wagon is tipped so that the whole of its contents are discharged in one slow movement with coal having a moisture content up to, say, 20 per cent. No obstruction is offered to the coal and hand trimming is unnecessary. The empty wagon is then returned to its normal position, weighed and run off the table, leaving the table free to receive the next incoming wagon. The weighing machines are integral with the tippler mechanism, and are fitted with a ticket printing recorder and totaliser. The printer prints the individual gross and tare weights on tickets and the totalising mechanism is capable of registering up to 9,999 tons. It incorporates locking gear and reversing ticket printing recorder. The automatic reversing drive causes loads weighed to be alternatively added or subtracted from the weight indicated by the recorder dial, thus the filled wagon is weighed and the gross weight recorded. The wagon is then raised, emptied and re-weighed, the tare weight of the wagon being subtracted from the previous record, leaving the net weight. Each machine is capable of weighing up to 30 tons, and is so designed that a moving load of 60 tons can pass safely over it. There should be adequate access in the tippler pits to facilitate inspection and maintenance of the driving gears, ropes, etc. A disadvantage of rotary tipplers is the necessity for replenishing wagon axle boxes

with oil, but wagon axle boxes designed for complete inversion obviate this. When wagons are shunted on to tippler type weighers the oil runs down the axle into the axle boxes. The boxes, not being in the normal vertical position, allow the lids to open and the oil falls out on to the weigher and platform. A simple axle box cover can be fitted which is of a mild steel strap construction and prevents the covers opening. A clamping arrangement is provided which has the necessary interlocking and reversible control gear operated by crank handle in such a way that the tippler motor cannot be started until the wagon is properly secured and the clamping gear cannot be released until the tippler comes to rest. Brass nuts on the clamping gear should be made in halves to facilitate replacement as solid nuts necessitate dismantling of clamping rods, etc.

An 8 B.H.P. motor-operated rotary tippler capable of handling 10-, 12-, 15-, and 20-ton wagons has a 2 B.H.P. clamping motor.

End-discharging tipplers are also used but suffer from the disadvantages that only wagons with end doors can be used, which limits the size of wagon that may be tipped ; also hanging up is frequent. The use of self-discharging wagons overcomes these difficulties. Some of the protecting fenders are far from satisfactory. A simple expedient is to provide a number of pieces of old car tyres bolted to the cross framework, which prove quite effective and stand up to the arduous conditions.

Receiving Hoppers. The construction of coal receiving hoppers has received considerable attention and some usual forms are :—

Steel hopper with blue-brick lining.
,, ,, ,, reinforced concrete lining.
,, ,, ,, rubber lining.
Plain reinforced concrete hopper.

Hoppers of steel plate construction lined with tiles have been used to withstand abrasive action when coke is handled.

The size and shape is governed by the maximum length of wagon, the valley angles necessitated by the class of coal handled and the storage capacity to enable the plant to operate at full load whilst the plant is in service. Assuming two 20-ton wagons to be discharged simultaneously, then the hopper capacity would be at least 40 tons. The classes of coal handled vary over a wide range and the valley angles of the hopper should allow free flowing of coal having a moisture content up to 20 per cent.

A hopper having angles of 45° for the sides and 50° for the corners has been found satisfactory for dealing with dry and wet slack. Where possible a minimum slope of 50° is recommended ;

any increase beyond this figure will of course tend to increase the depth of skip pit or feeder pit and entail additional civil engineering work.

To prevent the lodgment of coal, the corners of the hoppers should be well rounded. Trouble is sometimes experienced with the lower portions and mouths of these hoppers, due to perishing of the concrete caused by contact with wet coal, and to overcome this trouble the hopper outlets may be fitted with cast-iron mouthpieces. Coal contains a certain amount of pyrites and moisture so that it is necessary to take precautions against acid action. The material and construction adopted for these mouthpieces should ensure resistance to corrosion, easy replacement or quick repairs. The outlets from the hopper should each be fitted with a hand-operated rack and pinion cut-off gate. If both feeders operate from the same drive this gate enables one feeder to remain in service whilst the other is out.

Screening grids should be placed over the receiving hopper to prevent the ingress of stray lengths of props, wood and very large pieces of coal, etc., to the hopper mouths. Grids of 2-in. square mesh and others divided into long sections with flat bars on edge, spaced at about 4-in. centres with tube distance pieces at 12-in. centres, have been used. The receiving hopper pit should have a sump to take away any surface water.

Mixing Bunkers. It is sometimes necessary to arrange for mixing of coals and/or coke, and this may be done by having a bunker with two compartments. The chute at the head of the feeding conveyor will be of bifurcated construction to enable coal or coke to be delivered into either compartment. These bunkers are of steel plate, each compartment having a hoppered outlet designed to deliver coal and coke as desired to feeders. Owing to the excessive wear due to abrasive action of coke, it is advisable to fit shield plates to the sides of the coke bunkers. Coal chutes are often left unlined, but a $\frac{1}{4}$-in. or $\frac{3}{8}$-in. steel lining provides longer life and easier renewal. Cast-iron linings, bolted in position, give good service and plates of $\frac{1}{2}$ in. to $\frac{3}{4}$ in. thick and standard widths of from 12 in. to 16 in. have proved satisfactory. Setscrews and studs should not be used and bolts should never protrude through the nuts. The feeders can be adjusted so that the discharge to the conveyor can be regulated, and any mixture of coal and coke obtained.

Feeders. These may be of the rotary or jigging types and are placed immediately below the receiving hopper. The feeders are designed to take coal from the hopper outlets and deliver it to their

corresponding skips or conveyors without spilling. The feeders can only deliver coal when the respective skip is in the filling position and stops when the skip has received its predetermined amount of coal. When conveyors are in use these must be running.

Jigging feeders consist of mild steel trays which are given an oscillating motion through a connecting rod *viâ* a variable stroke crank, worm reduction gear and electric motor. Skirt plates run along both sides of the feeders to prevent spillage, these plates terminating in a head chute which delivers the coal on to the conveyor.

A rotary feeder consists of a circular steel table placed centrally below the hopper or bunker outlet, arranged to discharge the coal and prevent spillage. These may have common or independent drives. The former would have a clutch so that either or both feeders may be operated. Electric vibrator feeders are also used.

Loading Chutes. As an alternative to the use of feeders just mentioned, automatic loading chutes may be used and have the advantages that auxiliary driving gear and parts subject to considerable wear are eliminated, and, further, are cheaper. The loading chute is so arranged that as the skip fills the flow of coal from the hopper slows up and finally ceases due to the angle of repose of the material. The operation of the skip is controlled by an electrical timing device which ensures that it will not start until it is fully loaded unless, of course, there is no coal in the hopper. The design and construction of the chutes should be such that any part can be easily replaced or repaired, and the question of corrosion should also be kept in mind.

Access should be provided to permit of cleaning in case of stoppages.

Skip Hoists. Within recent years considerable attention has been given to the comparative advantages of elevators for raising coal to the overhead boiler bunkers. Bucket elevators were very popular in the early power stations when the quantities of coal to be handled were comparatively small. High capacity, high load factor stations require large quantities of coal and it is therefore necessary to have an equipment that has a high-rated handling capacity consistent with capital and operating costs incurred. The most economical conditions for electric hoists are high nett loads and low speeds and the use of skips in place of bucket elevators appears to be justifiable for power station service. A larger tonnage may be raised owing to the higher ratio of nett load to total load and the mechanical details requiring skilled attention are few.

Skip hoists which, while intermittent in their delivery of material, offer a means of elevation economical in both power and maintenance. The use of a twin-skip design reduces the size of the hoppers, and the plant can be arranged to discharge at different levels if required. Wear is especially concentrated on the skips and

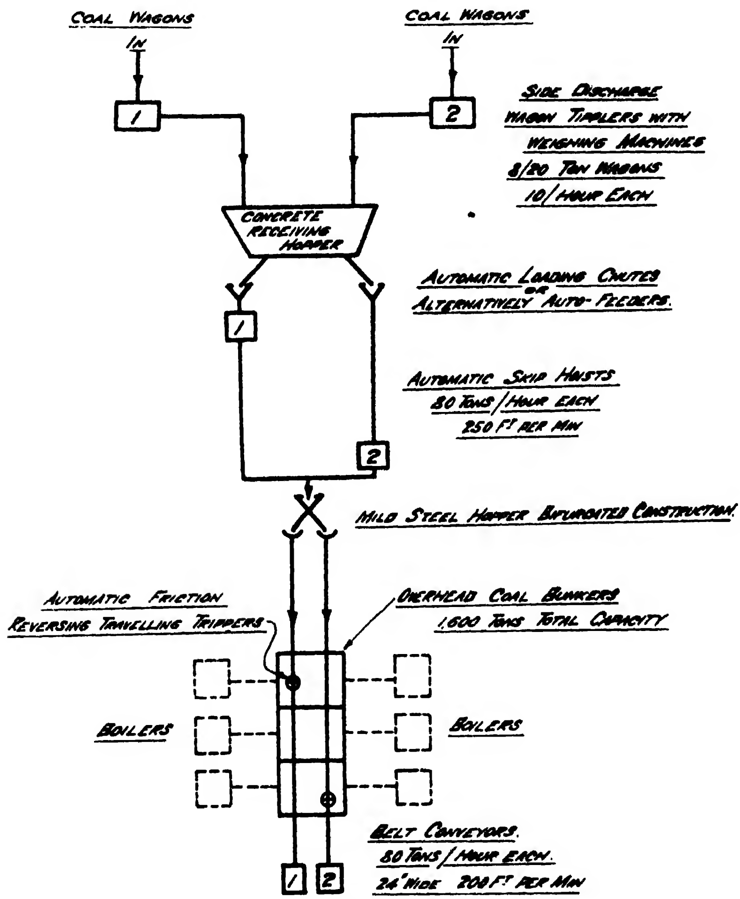


FIG. 96. Skip Hoists and Associated Plant.

ropes, both of which are replaceable. Fully automatic skip hoists (Fig. 96) are usually provided, each capable of elevating coal from the receiving hopper to the conveyor feeding hopper. The skips are designed to ensure clean discharge of the coal into the conveyor hoppers and are interlocked with the conveyors so that the skips can only operate when a conveyor is running, thus avoiding over-

filling of the top hopper. Skips can be operated with either of the conveyors. The skips should be designed so that spillage during the filling operation is a minimum. Cases are on record where trouble experienced from this cause was due to the counter weights on the loader being too heavy. In some cases the skips are independent, having balance weights, and are therefore able to operate separately whilst maintenance and repairs can be carried out on either. If the space is restricted it may be necessary to provide screen plates between each hoist tower to a height of about 12 ft. from the bottom to permit of maintenance without danger. Similar remarks apply to the drives or sheaves at the top of the skip tower. The skips and balance weights are fitted with shoes to enable them to be lowered gently to the bottom of the pit in the event of rope failure. The skips and balance weights work on steel guides fitted with renewable steel wearing strips and the drives are by electric motor through totally enclosed worm reduction gears. There are three types of drums which may be adopted: (1) cylindrical; (2) cylindro-conical; (3) bi-cylindro-conical. The first and second types are usually employed. The advantages of the second and third types are:—

(*a*) Reduction in capacity of driving equipment.
(*b*) Reduction in energy consumption, *i.e.*, increased winding efficiency.
(*c*) Reduction in maximum power demand.

These advantages result from the low torque required during the starting period as a result of equalising the rope pulls. The shorter the wind, or the shorter the full-speed period the greater becomes the benefit derived from a reduction of the power required during starting and stopping. The most effective distribution of turns consists in climbing the cone in the fewest turns practicable and completing the acceleration of the drum while winding on the small diameter. The diameters of the pulleys around which the ropes bend should be large enough to reduce excessive stresses in the rope. This applies to all equipment using ropes or belts.

The pulley groove section should be such that wear will not bring the rope into contact with the sides of the groove. The arc of contact with the pulley groove should not exceed 90° and pulleys should run perfectly true. Springs fitted at the load end of skip hoist and drag scraper ropes appear to increase the working lives of the ropes.

The storage of wire ropes is another feature worthy of attention for cases are on record where ropes held in store for a number of years

have failed after a comparatively short life. The chief cause of such failures appears to have been attributable to corrosion of the wires but the origin would seem to be due to loss of the internal lubricant. It is well known that the failure of steel ropes by corrosion of the inner wires has its source in the deterioration or loss of central lubrication, and the weakening of ropes is usually by needling or strand failure.

A steel-framed house is provided to house the skip hoist winches, access being either by stairway up the hoist tower or direct from the conveyor gallery. An alternative is to place the winch house at ground level and the advantages of this layout will be appreciated. The house is covered with protected metal sheeting with sheet lights for natural lighting, and doors for handling and access.

A runway joist and travelling pulley block, together with hand winch, are useful adjuncts to the winch house for handling conveyor belts and skip hoist and conveyor motors. The runway should project beyond the winch house to give a clear lifting position. Provision may have to be included for lifting the conveyor belts so that they may be rolled into position near the tail end of the conveyor gallery.

Conveyor Feeding Hoppers and Chutes. When two belt conveyors require feeding from one hopper, a common hopper of mild steel bifurcated construction is provided. The hopper outlets are fitted with rack and pinion cut-off gates so that, if one conveyor is out of commission, operation may be continued with the other. If one conveyor only is installed then a single-way hopper will suffice.

To allow for wear the sides of the hopper should have shield plates that are easily fixed and replaced. The design of the chutes should be such that the coal falls on to the belt without shock. This is attained by allowing the coal to flow on to the belt in the direction of belt travel and at the same speed as the belt. When the belt is reversible the feeding or discharge chutes will require a deflecting plate or door flap to feed the coal to suit the direction of belt travel. Chutes should be designed to feed the coal evenly and centrally on to the conveyor belts. The chute trough should be covered for a reasonable length on both sides to prevent spilling of coal. Unless these precautions are taken the belt life will be reduced. Coal chutes can be lined with glass or plastic plates to resist abrasion.

Conveyors and Elevators. These are of the belt or bucket types, although other types have been used with success. The

conveyors for boiler supplies are arranged to pass over the top of the overhead storage bunkers. Belt conveyors are fitted with travelling trippers (throw-off carriages) (Fig. 97), having chutes which discharge the coal into the bunkers on both sides of the conveyor. Where large quantities of coal are handled the belt conveyor can be operated at higher speeds than the bucket type. With bucket conveyors dumping arms are fixed at predetermined

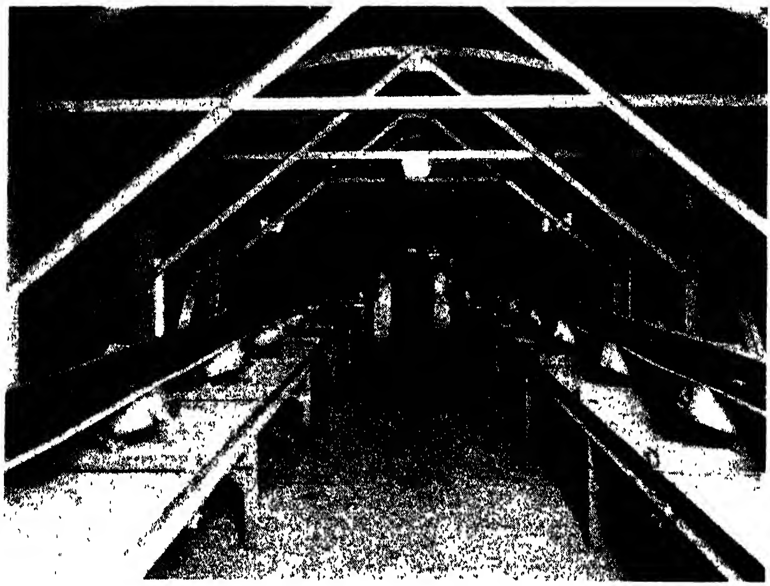


FIG. 97. Two 24-in. Belt Conveyors installed at Rotherham Power Station for handling coal into boiler house bunkers.

Capacity of each conveyor	100 tons per hour.
Length	250 ft.
Speed	260 ft. per minute.
Horse-power of motor	7½

Each is fitted with an automatic tripper. (International Combustion Ltd.)

positions. The trippers on belt conveyors may be of the automatic friction-driven reversing type, adjustable stops being fixed at intervals to permit the trippers to traverse any section of the bunkers. An alternative is the use of power propelled gear manually operated from the walkway. A brake or holding device should be fitted on one of the tripper leading wheels or framework to prevent movement of the carriage when placed in the neutral position. The braking or clamping should be positive to prevent the tripper running away. Cases are on record where the tripper has gained speed with the

handle rotating at high velocity. Three positions are provided for on each tripper: forward, neutral and reverse, the neutral position being used when discharging is required to take place in one position only. The operating arm for the valve in the discharge chutes should have adequate leverage to enable it to be worked with minimum effort. A chain-operated wheel is sometimes used and gives smooth opening and closing. Reversible shuttle conveyors are also used to distribute coal over bunkers.

The conveyors may be fitted with screw-operated or gravity-tension gear to adjust the belt tension and take-up slack belt. This gear should be of robust construction and designed to protect the screw as far as possible against dust, etc., when screw gear is used, and be accessible for adjustment and cleaning. The minimum take-up is approximately 1 per cent. of the length of a conveyor. Belt tension is maintained automatically by gravity take-ups. To guard against the possibility of the screw take-ups having unequal adjustment and so causing binding of the shaft, self-aligning ball races should be fitted. Ball-bearing idlers are fitted throughout, and have grease lubrication. The troughing idlers may be of the three- or five-pulley type, the curvature with the latter being more gradual, the profile of the idlers almost approaching the arc of a circle, thus preventing objectionable sharp bends to the belt under load and so prolonging its life. For belts up to 18 in. wide, troughing idlers of the three-pulley type are quite satisfactory, but above this the five-pulley type is recommended. At feeding points the troughing idlers should be grouped much closer to form a nest of idlers, and so increase the life of the belt and reduce spillage due to the belt sagging below the side seals. The theoretical horse-power for a belt conveyor is :—

$$\text{H.P.} = \frac{(0{\cdot}15\ W_1 + 0{\cdot}07\ W_2)\ S + HC}{33{,}000}$$

where C = capacity in lb. per minute.
W_1 = weight of belt, lb.
W_2 = total weight of material on belt at any one time, lb.
S = speed in ft. per minute.
H = height in ft. for inclined conveyors.

The life of a belt can be estimated from :—

$$T = 5.W^2.L$$

where T = average life of a belt in tons per hour.
W = width of belt in in.
L = centres in ft.

The life of a belt is also dependent upon the speed at which the load is carried, excessive speeds causing quick deterioration of the belt and high maintenance charges. High speeds are justifiable, but consideration should be given to the working conditions and the materials of the conveyor. Speeds of 250, 350 and 450 ft. per minute have been used for belt conveyors, and 500 ft. per minute and over for shuttle belts. Conveyors are arranged so that each run slightly faster than the conveyor delivering to it, thus obviating the possibility of congestion at transfer points. A long belt is not subject to the same amount of wear as a short one, since wear only takes place at the feeding point. The belts should be of the best quality rubber and canvas with $\frac{1}{8}$ in. thick and $\frac{1}{16}$ in. thick rubber on the carrying and return sides respectively and be specially protected along the edges against wear. Belts are often referred to as x oz. duck (*i.e.*, 32-oz. duck), the term duck is strong untwilled lined fabric. Conveyor lengths can be longer if nylon or rayon cords or steel wires are embedded longitudinally in the rubber. The number of drives and transfer points is decreased. One of the principal causes of belt destruction is edge wear caused by the belt running out of true. This can be overcome by adjustment of the troughing idlers during the initial training of the belt.

The rubber belt is an expensive item, and savings made by the installation of cheap belting invariably appear as costs at an early period in the life of a conveyor. In selecting a belt for any specific duty the following should be considered:—durability, strength, toughness, atmosphere (steam, fumes, moisture), elasticity to absorb shocks from fluctuating loads, freedom from excessive stretch, lightness, pliability, ability to elongate and return to original length without undue heating, high tractive quality, length, speed and type of drive.

The conveyor pulleys are of heavy cast-iron construction having machined crowned faces, the driving pulley being faced with ferodo or other similar friction material. The diameters of pulleys around which a belt bends should be large enough to reduce belt stresses. The diameters of the head, tail, snub and bend pulleys depend on the thickness of the belt and a useful rule is:—

Head pulley	5 × belt ply
Tail pulley	4 ,, ,,
Snub and bend pulleys	3 ,, ,,
Tripper pulleys	5 ,, ,,

The diameters are in inches.

The width of the pulleys will be generally as follows :—

Head pulley, 2½ in. wider than belt.
Tail, snub, bend and tripper pulleys, 2 in. wider than belt.

A snub pulley is used to relieve the adjacent return idler and increase the arc of contact of the main pulley.

Conveyors are driven by electric motors through totally enclosed worm-reduction gears. The motor, reduction gear and head pulley should be mounted on a common bed plate. One-piece bed plates (welded if desired) are preferred, integral with the driving shaft supports to preserve alignment, and flexible couplings are fitted between the motor and the gearbox. With a fabricated construction care should be taken to make it as rigid as possible. For other than level conveyors, a solenoid brake or automatic rachet may be included to prevent run-back when the conveyor is stopped.

Belt cleaning gear should be provided at the head end of each conveyor also on each tripper to clean off damp coal-dust and so prevent it being carried on to the return idlers. When the belt runs in both directions it is necessary to include cleaning gear at each end. Two types are a rubber scraper and a brush. The cleaning in the latter is by means of a brush, chain driven from the head pulley. The carrying side can be cleaned by a rubber scraper as it leaves the head pulley, and a steel scraper cleans the snub pulley over which it next passes. The belt is therefore preserved from fine materials being ground into it and the pulleys are kept clean, which ensures that the belt continues to run straight.

The cleaning gear should always be in contact with the belt and designed so that obstructions will not interfere with its operation or cause tearing of the belt in the event of a fastener opening or breaking. The efficiency of belt wipers depends on : stickiness of coal, size of coal and belt wear. A small chute connected to the coal bunker, or a receptacle which can be emptied may be provided at the head end of each conveyor to carry off the " smalls " which would otherwise be deposited on the floor beneath the driving pulley.

The conveyor tracks should be fitted with sheet steel decking plates or inverted troughing, to protect the return side of the belt from falling coal and also prevent coal falling to the ground where the conveyors are outside the boiler houses. Where the majority of the coal handled is duff, care should be taken to keep it from building up on pulleys or sticking at transfer points.

For successful operation of belt conveyors it is important that

they are run in a straight line, kept clean, fasteners put on correctly and maintained in good order, and given reasonable attention.

The bucket type of conveyor and elevator has been employed in small and large stations. These elevators are quite satisfactory if attention is given to bucket design and methods of fixing, and the vertical type is preferred to the inclined type, since less space is required ; skids and skid bars are eliminated, a minimum of lubrication is necessary and an almost silent elevator is obtained. The buckets are made of malleable iron or mild steel plate pressings assembled in a substantial manner to form a continuous chain.

The materials of guides, links, bushes, etc., should be sound, have good wearing properties and the parts should be as simple as possible. Considerable damage can be done due to failure of links causing complete collapse of an elevator. An observation door in the elevator casing at a suitable height above ground level enables the attendant to watch operation of elevator and note defects. Removable sections of casing near sprockets facilitate inspection and maintenance. Each bucket in the length of the elevator can be connected together by means of a wire rope and so minimise risk of complete collapse. This has been done on old types of bucket elevators and conveyors and it is simple and cheap The speed of the buckets varies with the load, *e.g.*,

100 tons per hour—50 ft. per minute (60 80 common)
30 tons per hour—120 ft. per minute.

Gravity bucket elevators are operating satisfactorily with capacities up to about 200 tons per hour.

Bucket elevators are supplied with coal through a bucket-filling mechanism which may be of the rotary type operated from the elevator chain. The fillers load each bucket with the correct amount of coal without spilling, a regulating slide or valve being included for this purpose. The bucket elevators may have two revolving fillers, thereby enabling alternate buckets to be filled with different classes of coal to facilitate mixing. Chain sprocket wheels are sometimes fitted with renewable rims which reduce replacement charges.

The tension gear should then be mounted on a rigid steel framing and the stretching screws should be of adequate proportions. A square thread is preferred to a Vee thread for these adjusting screws. In some installations this item has given much trouble due to its flimsy design resulting in slackening off, etc.

Bearing lubrication arrangements should ensure a grease seal being maintained at the ends in elevator casing. Probably the most

important factor in keeping elevator and conveyor maintenance costs down is to maintain them clean and well lubricated.

The horse-power required to drive an inclined elevator can be obtained from :—

$$\text{H.P.} = \frac{\text{M} \sin \theta}{33{,}000} + \frac{\text{KS(M} + \text{C)} \cos \theta}{33{,}000}$$

where M = weight of material in elevator, lb.
C = weight of chain and buckets, lb.
K = 0·2 for skidder bar chains ;
0·1 for roller type chains.
S = speed ft. per minute.
θ = angle from horizontal.

To this theoretical horse-power should be added an allowance for starting up under load and multiplied by 1·5, to allow for gears, pick-up in the boot, etc.

The drag-link or scraper type of conveyor has been used but is not favoured generally The chief disadvantages are high power and maintenance charges.

The conveying of coal by mixing it with water and pumping it through pipes has been tried and is found to be cheap and simple.

A belt elevator with buckets attached is also in use but the method of feeding requires further development and the system generally has not been tried over a lengthy period.

A conveyor may be arranged for water conditioning of the coal, by spraying and this contributes to good combustion.

Gangways should be provided in the centre and on each side of the conveyors to give access to all parts throughout the entire length of the conveyors. Hand-railing and guard rails should be included and gangways of open-mesh steel grid floor are quite suitable for this purpose.

Staircases should be arranged at an angle not greater than 45° with the horizontal with stair treads at least 9 in. wide with 11 in. toe room and risers at a constant height throughout, and never more than 8 in. high. Landings can be arranged at intervals not exceeding 10 ft. to prevent fatigue of the user and to minimise the risk of serious fall. Aluminium alloys have been employed for handrailing and roofing purposes and appear to be satisfactory.

To enable the attendant to get from one conveyor to another without having to walk to either the driving or tail ends to do so, a cross-over gallery should be placed at approximately midway along the length of the conveyor track. The bridges outside the

boiler house consist of a steel-framed structure covered with protected metal corrugated sheeting. The roof may have two sheets and the sides a single sheet with sheet lights at regular intervals to provide natural lighting.

A better finish of the roof and floors may be obtained by using reinforced concrete, the walls being a water-proofed concrete plaster on "Hy-Rib."

Automatic Railway. This is sometimes employed where coal has to be delivered from a high siding to a lower level, the gradient of the railway being such that the energy developed by the loaded truck passing down the incline is sufficient to return the truck to the starting point after discharging. The discharging and return of empty truck is automatic.

Magnetic Separators. Separators are provided to rid the coal of tramp iron, which finds its way into the coal at the collieries, and takes the form of coal cutter teeth, bolts, nuts, wire, fish plates, etc. A small amount of bolts and nuts may enter the coal from the feeders, conveyors and elevators, and it is therefore desirable that the separator be placed as close as possible to the coal-preparation plant, and in any case before passing on to the storage bunkers.

Magnetic separation is more desirable with pulverised fuel than stoker-fired plant. The latter will pass tramp iron without any risk of damage, but the feeders and milling plant associated with the former may be damaged.

With belt conveyors the head pulleys can be arranged as magnetic pulleys where the layout of handling plant permits. The points requiring attention if magnetic separation is to be efficient are depth of coal on belt and speed of belt. A magnetic pulley of given diameter has a maximum depth of feed, and if this be exceeded separation cannot be guaranteed. On a very long belt it is possible for tramp iron to take up gradually a lower position near the belt and so come under the influence of the pulley to a greater extent. In the case of a thick feed on a narrow belt a larger diameter pulley may be used, and to maintain the belt speed this can be run at a slower speed. By increasing the pulley diameter there will be a considerable increase in the magnetic field.

It has been suggested that the most efficient speed for a magnetic pulley or drum is between 30 to 40 r.p.m. There are two chief classes of separator in use, the self-cleaning magnets and those which have to be cleaned manually. Magnetic pulleys automatically discharge the extracted tramp iron, but suspension and chute magnets

need to be shut down for periodical cleaning. The construction and operation of the magnetic pulley is simple: the magnetic circuit consists essentially of the poles and the cores, both being of circular form. The magnetising coils are wound on steel bobbins heavily insulated and held securely in position and collector gear is fitted. The magnetic fields can be varied to suit requirements, the pulley being arranged with the necessary poles separated by non-magnetic covers.

Crushers. Many types of crusher are in service which are designed to take "run of mine" coal and reduce same to a suitable size. The outputs of the crushers are such as to deal with the maximum working conditions. Crushers are not installed in all stations, and when they are it is usual to include arrangements for by-passing them should the coal not require crushing.

If crushers are used regularly, they may prove to be expensive, due to: higher price charged for the large coal received; cost of crushing; and combustion may be impaired because of the relatively higher proportion of duff unavoidably produced and carried into the boiler furnace.

Grabs. Grabs are generally associated with telphers and cranes and form an important link in many coal-handling plants. In whatever form they are applied their adaptability to difficult positions, robustness and simplicity have justified their inclusion on power station sites. For water-borne coal the grab is now commonly employed for unloading purposes.

Grabs are operated by chains or ropes and there are various types: double- and single-chain grabs, twin- and four-rope grabs. Multipe-rope grabs prevent spinning, which is useful when required to operate in confined spaces, such as wagons and barges. The grab is a one-operator machine. The load taken is governed by the supporting structure, runway or crane, but apart from this it can be designed to meet the needs of a coal-handling plant.

Shunting Locomotives. Well-laid-out sidings for dealing with coal and ashes are essential in a high-capacity station and where possible it is desirable to surround the whole station with railway tracks, some being taken to various sections of the buildings and plant. The site layout may make it impossible to deal with the entire area by capstans, and it becomes necessary to provide a shunting locomotive.

The site will primarily decide what type of locomotive can be used, then the question resolves itself into an economic one. The choice will be from electric, steam or diesel locomotives. Electric

and steam shunting locomotives have been used and have given satisfactory service over many years. Electric operation necessitates an overhead conductor system (Fig. 98) throughout the site, but this is offset to some extent by the reduced working costs. An alternative is the battery-driven locomotive which has proved very popular. The steam locomotives may be of the fireless type, being charged from steam connections in the station.

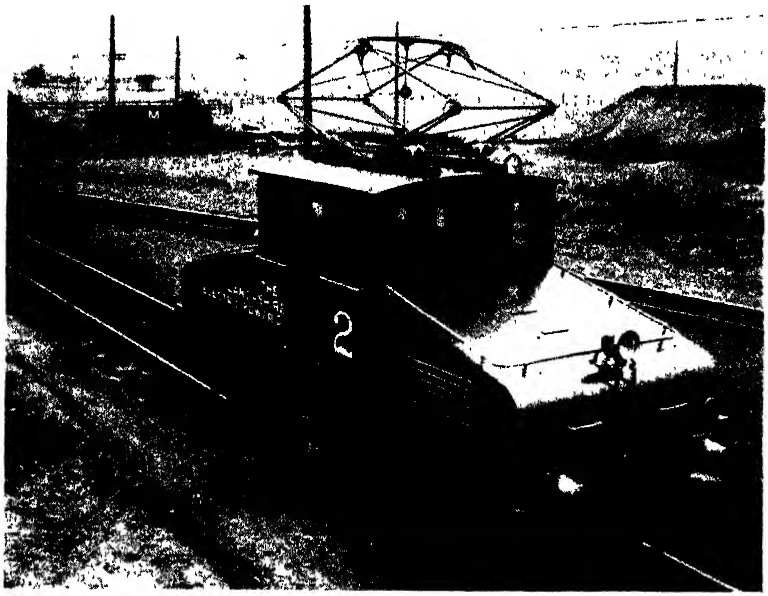


FIG. 98. Electric Shunting Locomotive at the Kearsley Power Station. (British Thomson-Houston Co. Ltd.)

Comparative costs of locomotives are generally as follows, but special requirements may well add to the cost in each type :—

Steam	1·00
Diesel—Mechanical	1·65 1·85
,, —Electric	2·25 -2·50
Fireless	0·90 -0·95

Locomotive Crane. This is a useful machine for ship unloading and can also do shunting and lifting on the station site. It is flexible, fairly cheap and reasonably low in maintenance.

Grabbing Crane. The need for a coal-grabbing crane of the caterpillar-track type on some sites is very important as deliveries of coal by both rail and road are sometimes extremely irregular,

thus necessitating repeated withdrawals from the emergency coal stocks. Some thousands of tons of coal may require to be reclaimed from the emergency stocks to keep the station in service. To deal with the quantities of coal which may have to be handled an efficient coal-grabbing crane should be available, for to carry out the work by manual labour, even if it were possible, would be a costly matter and regard must also be had to the fact that labour of a suitable type may not be available.

A crane capable of stacking coal to a height of 12 ft. with a crane radius of 20 ft. and grab capacity 1 ton is very useful for such work. A diesel engine drive is used. Such a crane may be required to operate over uneven ground which becomes soft in wet weather.

Weighing of Coal. The quantity of coal sent into a station must be checked and recorded as required, *e.g.*, a consignment of coal may be partly required for immediate use and partly for storage, and records must be kept of how this has been allocated. For small stations the usual weighbridge is quite suitable, but where large quantities of coal are dealt with automatic weighers are essential.

When wagon tipplers form part of the handling plant the weighing operations can be carried out during unloading. A fully automatic system may be used when unloading by grab from colliers; the quantities delivered to the bunkers or put into storage are therefore easily ascertained.

The coal supplied to the individual boilers is also measured by the inclusion of automatic weighers between the bunkers and the milling plant or stoker, depending on whether pulverised fuel or stoker-fired boilers are in use. Methods of measuring coal are discussed under Boiler Plant. Some typical forms are included showing how coal may be recorded.

Control House. The choice of position and the type of building required for carrying out control of coal-handling operations will depend primarily on the methods of handling in use. In some cases the control centre is merely a protected metal-sheeted cabin, which is very cheap and no doubt serves its purpose well. With the large plants now being installed it is well worth while paying attention to the design, layout and methods of control.

The control house can be made the centre from which all coaling operations are directed, and particular attention should be paid to its position, building construction and layout of plant housed in it. Features of importance are accessibility, observation and communication. There are no hard and fast rules which apply to all

WELLFIELD CORPORATION ELECTRICITY DEPT.
WELLFIELD POWER STATION
DAILY REPORT

To RECORDS CLERK *Date*.........................

No. of Boiler	Steaming					Banking				
	Hours	Coal Consumed				Hours	Coal Consumed			
		T.	C.	Q.	Lb.		T.	C.	Q.	Lb.
1										
2										
3										
4										
5										
6										

Total Coal Consumed........T........C........Q........Lb.

Signed.......................................
Charge Engineer.

Calculation of Coal Consumed

For month ending.................194 . .

Week ending ....194 .

	Advised weights T. C.	Weighbridge weights T. C.
Coal in bunkers midnight . . .		
Coal put into bunkers during period. .		
Coal in bunkers midnight . . .		
Coal consumed as per bunkers. . .		
Coal consumed as per daily returns . .		

Units Generated.	Coal per kWh per Bunkers.	(Advised weights) per Daily Returns.

Weekly Analysis of Coal Advised

Week ending..............................

Supplier	....			....			....			....			....
Date	Wgs.	T.	C.	Wgs.	T.	C.	Wgs.	T.	C.	Wgs.	T.	C.	Wgs.

Coal Burnt from Topping up Bunkers to Midnight

To Station Clerk. *Date*..

Boiler Coal Meter Readings	Boiler No. 1		Boiler No. 2		Boiler No. 3	
	L.H.	R.H.	L.H.	R.H.	L.H.	R.H.
Readings at midnight .						
Readings at time of last topping up of bunkers						
Difference . . .						
Equivalent in tons per boiler.						
Tons coal remaining in coal flow.						

Time	No. 1 Set	Aux.'s	No. 2 Set	Aux.'s
24·00				
Difference				

Bunker's Tonnage at Midnight	
No. 1 bunker	
No. 2 bunker	
No. 3 bunker	
Total . .	

Signed ....

Charge Engineer.

sites or methods of coal handling, but the time spent on planning is justifiable, and more so as the station increases in capacity.

The house may be constructed on similar lines to the main buildings in so far as architectural features are concerned; brick and reinforced concrete are quite common.

To obviate the accumulation of large quantities of coal dust the surfaces should be such that lodgment of dust is reduced to a minimum. A curved roof, supported on arches, would therefore meet these requirements.

When wagon tipplers are employed the control house can be placed alongside the receiving hopper. If the hopper is some considerable height above ground level, as with side-discharging wagon tipplers, it is advisable to raise the control house to such a height that the operator has a completely unobstructed view of the whole equipment. Ample window space is necessary, particularly on the front and sides. The chamber immediately below can be utilised as a switch house, the transformers being placed outdoor nearby.

The whole of the coal-handling plant may be arranged for control from this house, and it should be the only point in the entire system from which it is possible to isolate normal control and change-over to "test" control. Centralised control possesses certain advantages, some of which are :—

(1) It enables the control gear to be grouped in one house remote from dust and dirt.

(2) Groups of motors controlled from one position improve operation, since starting and running of the plant is simplified.

(3) Main cabling and switchgear is simplified whilst the control circuits can be arranged in orderly groups.

A telephone system for transmitting instructions should be included with connections to all important operating positions throughout the coaling plant. The lighting of the sidings, storage areas, etc., may be controlled from this house.

Purchase of Coal. The class of coal used is controlled by the requirements of the boiler and handling plants installed, *e.g.*, stoker or pulverised fuel-fired boilers. Good buying depends on having as wide a specification as possible, but particular attention should be paid to guaranteed sizing figures, etc. The fuel purchasing officer has no easy job when offers have to be compared from a wide range of coals. Speaking generally, the best way is to play safe and stand by the class of coal which has proved satisfactory under all known working conditions. To purchase an unknown cheaper class of coal may at first sight appear to give a saving on a large contract, but

WELLFIELD CORPORATION ELECTRICITY DEPARTMENT

COAL ANALYSES REPORT. CHEMICAL AND TESTING DEPT.

Received from...................................... *Week Ending*.................194...

Name of Coal	Description of Coal	Supplier	No. of Wagons Sampled	Proximate Analysis (as received)				B.Th.U. Gross		Remarks
				Moisture Total	Volatile Matter	Fixed Carbon	Ash	Wet	Dry	

Average calorific value of fuel raised to station bunkers........... B.Th.U's/Lb.

Report on Coal Sample

Source .... Date ....

Name of Coal.............................. Merchant..............................

Description .... Wagon No..............................

Price per ton.............................. B.Th.U.'s per lb..............................

General appearance ....

Proximate Analysis :

	Air Dried Coal	Calculated to		
		As Received	Dried	Dry Ash Free
Surface moisture . .				
Hygroscopic moisture .				
Total				
Volatile matter (less moisture)				
Fixed carbon . . .				
Ash . . .				
Total	100	100	100	100
Total sulphur . . .				
Combustion sulphur . .				
Calorific value . . (B.Th.U. per lb.)				
Remarks :—				

Sizing Test :

	Per cent.
Over ½ in. sieve . . .	
Through ½ in. sieve over ¼ in. sieve	
,, ¼ in. sieve . . .	
,, ⅛ in. sieve . . .	
Total . . .	100

Colour of ash..............................

Character of coke.....................

Melting point of ash...........

Signed..

large-scale extensive trials should first be undertaken and even then it is still possible to be let down. The most important factors affecting efficiency are the different characteristics, heat value and size of the coal. Few coals have the same characteristics even though the heat value may be similar, and efficient results cannot be obtained unless the peculiarities of each coal are carefully considered.

In order to burn certain coals efficiently it is essential that they should be mixed with other coals, but such mixing requires care. It may be necessary to have separate bunkers for different coals, and intimate mixing is necessary before delivery to the boiler bunkers. Some coals (slack or duff) burn better when wetted, and it is possible to obtain higher combustion chamber temperatures and a higher CO_2. Apparently some improvement is effected due to the moisture expanding and moving the particles of dust coal apart, thus allowing more even access of air through the fuel bed. Unless duff coal is wet it goes over the grate like a blanket and at a low chamber temperature, and if the draft is increased too high it breaks up the fuel bed into ridges through which large volumes of excess air enter the combustion chamber, thereby lowering its efficiency. The legislation controlling production and selling of coal has also to be reckoned with, and a number of undertakings have raised the following complaints :—

(1) The prices quoted are unfair, inequitable and contrary to the public interest.

(2) A considerable portion of the coals offered is of a low quality and unsuited for the requirements of an electricity undertaking.

(3) The quota for the district is insufficient to enable the individual colliery undertakings to offer adequate supplies of the quality of coal required.

To illustrate the case in point, an electricity undertaking advertised for 700,000 tons of coal and subsequently obtained tenders for 600,000 tons, but only 300,000 tons were offered from the local collieries. It was contended by the undertaking that the advantage of the geographical position of the station was partly lost; which would appear to be a reasonable complaint. Further, the price of coal had increased by between 6*s*. to 7*s*. per ton over a period of some four years. With the advent of nationalisation of the coal mining and electricity supply industries in this country improved programming of supplies to power stations has been facilitated. Fig. 99 shows the average price of coal supplied to one Yorkshire power station.

No doubt the increase in price of coal to electricity undertakings has been precipitated by the increased capacities of modern power

stations. It is more difficult to buy large quantities of coal at a low average price than to buy small quantities at a low price. The development of electricity supply has had its effect on the coal mining industry in that as development increased the demand for domestic and industrial coal in turn decreased. In order to equalise matters it has been suggested that undertakings should

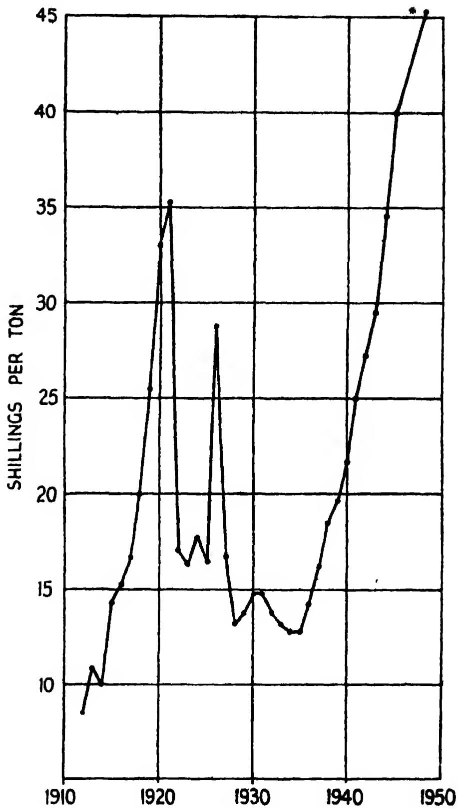


FIG. 99. Average Price of Coal.

use a proportion of screened large coal and crush it at the stations to a size suitable for consumption in the boilers.

Coal can be bought on analysis, penalty clauses being included to protect the purchaser where guaranteed figures are not obtained, after allowing agreed tolerances. This necessitates constant sampling and testing of all coal delivered to the station. A scoop with extended handle enables coal to be taken in stream flow from rail wagon and road vehicle. Another type of coal sampler embodies

a hinged scraper arm which is operated by a thrustor through a link mechanism carrying the scraper across the width of the conveyor belt. The scraper moves a cross-section of the coal and delivers it into a side chute. The driving motor is totally enclosed, fan cooled. A scoop-type coal sampler takes samples from a conveyor at the rate of twenty-two samples per hour in one plant. Should the coal be very wet (15 per cent. moisture or more) and sticky, considerable trouble will be experienced on elevators, in bunkers and coal chutes leading to the stoker hoppers or milling plants. Ash and sulphur contents are important characteristics and have considerable influence on the operation and maintenance of boiler plant. Coals of high ash content impose greater duty on the ash-handling plant and also affect the stoker (and possibly pulveriser) performance. Ash in coal affects : (1) Transport and handling of coal ; (2) Boilers require more cleaning ; (3) Removal and disposal of ash and clinker ; (4) FD and ID fanpower ; (5) Repairs and maintenance of coal-handling plant and grit arresters ; (6) Grinding with pulverised fuel plants ; (7) Loss of combustible in ash ; (8) Capital charges on boiler plant. Coals of high sulphur content (3 to 5 per cent.) result in serious boiler outages owing to the formation of hard deposits on air heaters and tubes. Samples may be taken for either of two purposes :—

(1) To test the quality of a consignment of coal as received.

(2) To determine the average quality of the coal supplied to a boiler over a given period or in a boiler trial. The general requirements regarding sampling and testing are given in British Standard Specification No. 735/1937. The conditions under which the plant is operated will also influence the class of fuel to be used, whilst the question of ash disposal should also be borne in mind. Typical coal analysis reports are shown. As a means of fuel comparison the following rule is useful :—

$$\frac{\text{B.Th.U. per lb.} \times 2{,}240}{\text{Price per ton pence} + \text{ash-handling charges}}.$$

Coal may be roughly classified as follows :—

Class	Volatile Matter, per cent.	Fixed Carbon, per cent.
Anthracite	3 to 9	83 to 90
Semi-anthracite	9 to 17	75 to 85
Semi-bituminous	17 to 25	60 to 75
Bituminous	25 to 40	40 to 60
Gas coal	40 and upwards	60 and below

Generally, the higher proportion of fixed carbon the higher calorific value of the coal. The proximate analysis will show the percentage of volatile matter, ash, moisture, and fixed carbon

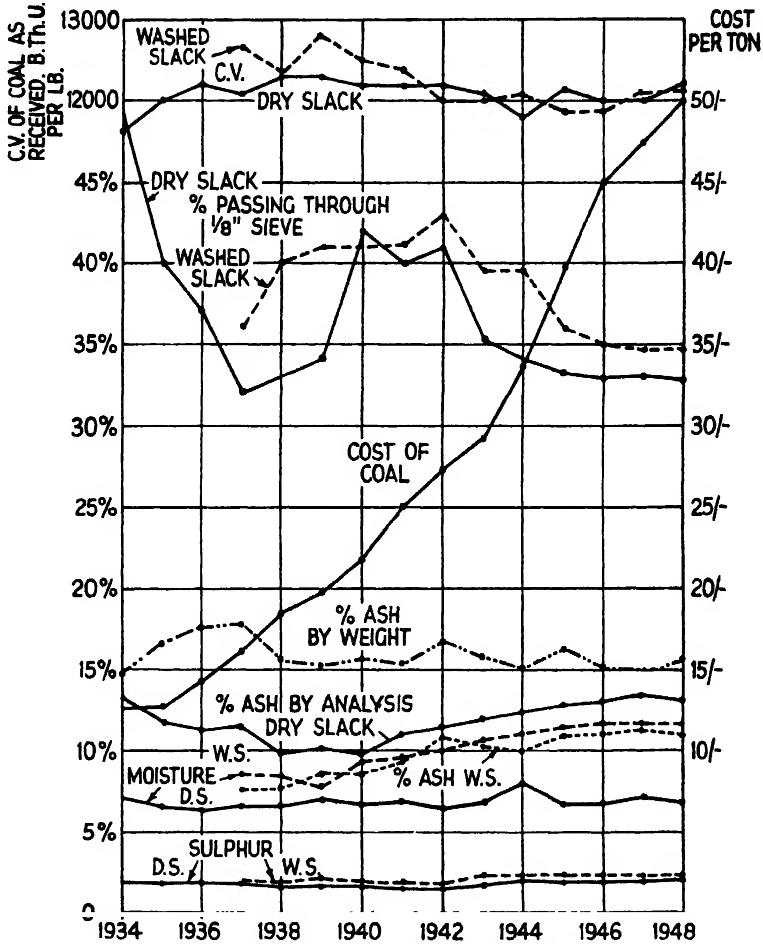


FIG. 100. Data for Deep-mined Coal.

contained in the sample tested. Brown coal of 2,900 B.Th.U. and 65 per cent. moisture has been used abroad for power station service.

The calorific value of the coal may be given as either a gross or net figure and the first is usually preferred. It does not, however, allow for the fact that all available heat is not usefully employed,

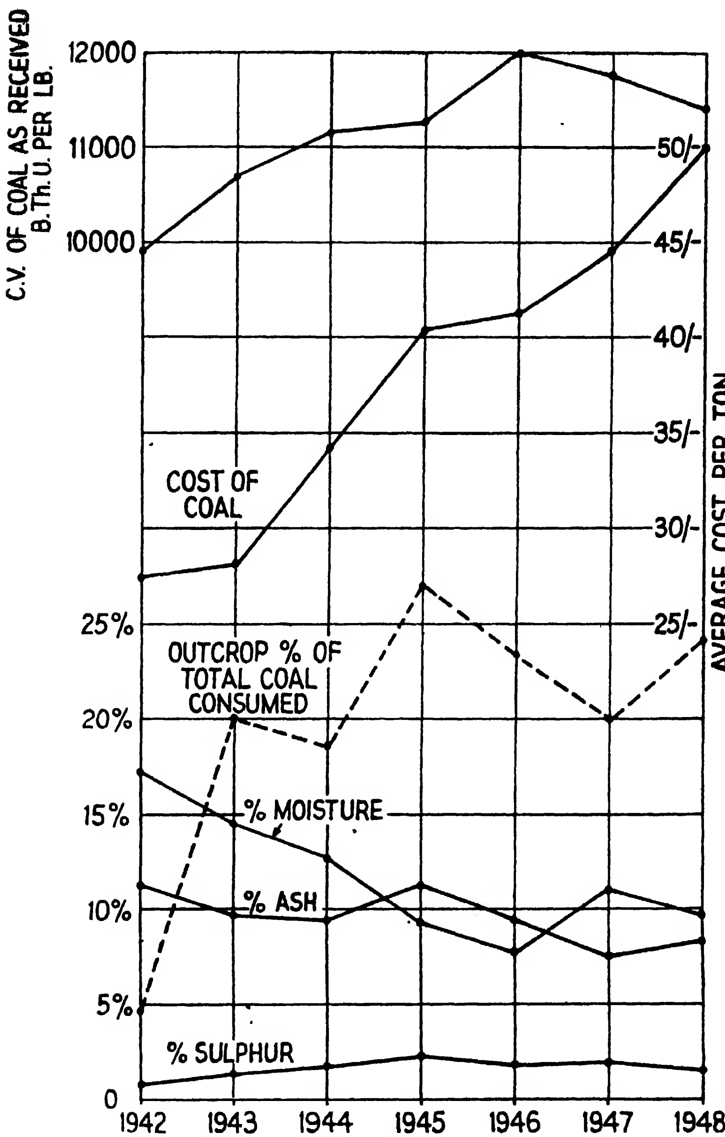


FIG. 101. Data for Outcrop Opencast Coal.

since vapour initially in the coal, plus that resulting from combustion of the hydrogen in it, is carried away in the flue gases. It can be determined by calorimeter with reasonable commercial accuracy. The net calorific value is based on assumptions and may

be differently interpreted. In practice it now entails a fixed conventional deduction of 1,050 B.Th.U. per lb. of water as the latent heat of condensation (see Chapter XX, Vol. II). Figs. 100 and 101 show characteristics of some of the coals used in a Yorkshire power station.

Storage. The problem of coal storage should be carefully considered and whatever methods are adopted they should meet all conditions of operation with a minimum of expense. Factors to be considered are: ground area and rent thereof, risk of spontaneous combustion, losses on storage and deterioration of coal, interest on capital cost of coal lying dormant, cost of insurance, handling costs necessitated by storage and reclamation, ability to overcome fire, local conditions of wind and climate.

The area chosen should be adequate for the ultimate requirements of the completed station. Assuming coal to weigh 50 lb. per cubic foot and the height of storage heap not to exceed 10 ft., then the area required to accommodate 10,000 tons would be

$$\frac{10{,}000 \times 2{,}240}{50 \times 10 \times 9 \times 4{,}840} = 1 \text{ acre approx.}$$

The sizes and heights of coal heaps vary considerably since much depends on the nature and size of coal, the method of storing and the storage area.

The ground should be dry and level, preferably a concrete floored area, whilst admission of air should be as small as possible. Gantry legs, drains and coarse cinder bottoms should be sealed to prevent the ingress of air to coal heaps. Different classes of coal should not be deposited in the same heap, and all sizes should be well mixed. Large diameter vent pipes are not recommended for they may do more harm than good.

If heaps of, say, 20 to 30 ft. are required, rolling and packing are necessary to prevent fires. A compressed coal pile is built up in layers so that all voids between lumps are filled with fine particles. This excludes air from the pile and retards spontaneous combustion. If there is any doubt about the storage of new coals it is advisable to include small pipes, say ½ to 1 in. diameter, for insertion of thermometers at various positions throughout the storage area to enable a watch to be kept on the temperatures. It has been suggested that 130° F. is about the limit for continuous safe storage and at 150° F or above the surrounding coal should be used or moved to cool off. The only safe way to deal with a coal fire is to dig out the area affected as quickly as possible. Playing water on burning heaps aggravates

matters and if digging out is not possible then the heaps should be smothered with sand or soil.

There are many forms of storage some of which are:

(1) Stacking the coal in heaps over available open ground areas.

(2) Ditto, but placed under cover or alternatively in bunkers.

(3) Allocating special areas and surrounding these with high reinforced concrete retaining walls.

(4) Similar to method (3), but arranging these areas below normal ground level so that the coal may be completely immersed in water, *e.g.*, old dock basins and gas holder pits.

The methods of storing coal will dictate the types of storing and reclaiming plants required. Storage hoppers or bins are used for small stations and may be of wood, brick, cast iron, steel plate or reinforced concrete. To counter the fire danger from internal combustion coal can be enclosed by a 10 ft. retaining wall which denies winds access to the sides of the stockpile. The coal, being stacked by bulldozer, is thoroughly compacted and thus, with the protection of the sides, effectively prevents air circulation in the interior of the pile and inhibits the outbreak of fire.

Provided land is available and not too costly, outside storage is cheaper than internal overhead storage, hence the tendency is to store coal mainly in the open and to provide only a limited amount of inside storage. With adequate outside storage, together with reasonable size inside bunkers, it is possible to draw from various classes and meet changes in electrical load fairly quickly.

The "Bulldozer" may be used to augment the usual outside storage equipment and this enables coal to be pushed to whichever part of the stockyard is most convenient. The 'dozer is a tractor machine having a large scooper or scuttle attachment in front, and is driven by internal combustion engine. It has the great advantage of flexibility of application since it can be used on any stock pile in almost any path. A 75 H.P. machine can handle over 100 tons per hour with a range of 30 to 40 yds. Wing plates attached to the U-blade of a bulldozer increase the "move" capacity within the capacity of the machine.

A few notes on some of the plants used will be of interest and the illustrations show their application.

Transporter Storage. The transporter has been used where large storing and reclaiming capacities are demanded. A large storage area of rectangular shape with facilities for either sea- or rail-borne coal is usual.

Coal can be stored and reclaimed as desired, the travelling

transporter being fed by conveyor and operated at any position in the length of the heap. The transporter discharges to the heap by conveyor and reclaims by grab to a conveyor.

One very large station used over 25,000 tons per week, six colliers with an average of 4,200 tons each being unloaded weekly.

Two ships of this size can be unloaded simultaneously and with seven jetty cranes working under the best conditions coal is handled in shore at the rate of 1,600 tons per hour. Under average tide conditions a 4,200 ton collier is normally unloaded in nine working hours. The storage capacity at this station is suitable for 220,000 tons of coal, and this is catered for by transporters.

For a station of ultimate capacity 500 MW, the coal-handling plant was designed for 400 tons per hour, carried out by self-unloading boats discharging on to a dock serviced by a 350-ft. span gantry crane and a cantilever over the dock, 165 ft. long, permitting a travel of 150 ft. A grab bucket of 6½ tons capacity discharges either to storage or to a hopper feeding a horizontal belt conveyor running parallel to the crane track. The coal is then taken to an inclined belt to the transfer house, where it is transferred to a second inclined conveyor at right angles which feeds the bunkers. Storage is provided for 200,000 tons of coal with an additional 50,000 tons along the dock.

Drag Scraper Storage. The coal is delivered by conveyor or elevator to an initial heap from which the scraper spreads it over the storage area. The scraper can dig from any part of the area and deliver it to a hopper, from which it is elevated or discharged to wagons and taken to the boiler bunkers. When travelling forward the scraper digs and fills quickly, but uniformly, and when full the digging process is stopped and the scraper with its load rides on top of the heap when conveying to the hopper. The advantages of this method are : storage area of irregular shape and varying level can be used ; low capital cost ; low maintenance and repair charges, low operating cost ; robust and simple in design and operation ; immune from firing ; will fit any storage area ; facilitates fire fighting ; it is able to operate in severe frosts and heavy falls of snow. The disadvantages are : cable wear, coal breakage, and moving of tail blocks. The latter is obviated by using a moving car on a track around the circumference of the storage area to carry the tail blocks instead of using post anchorages. A double-drum friction winch is employed to drag an open-bottom bucket fastened to an endless wire rope, from the receiving pile to the storage area

and then return empty to its starting point for a new supply. By reversing the bucket and dragging it across the coal heap to the feeding hopper, coal is reclaimed.

For storage areas of about 3,000 tons minimum, fixed anchorage posts at regular intervals (connected by wire ropes fitted with rings) enable the guide sheaves to be placed for different directions of motion of the bucket. A movable car running on a rail track is usual for larger storage areas. The entire storage area cannot be

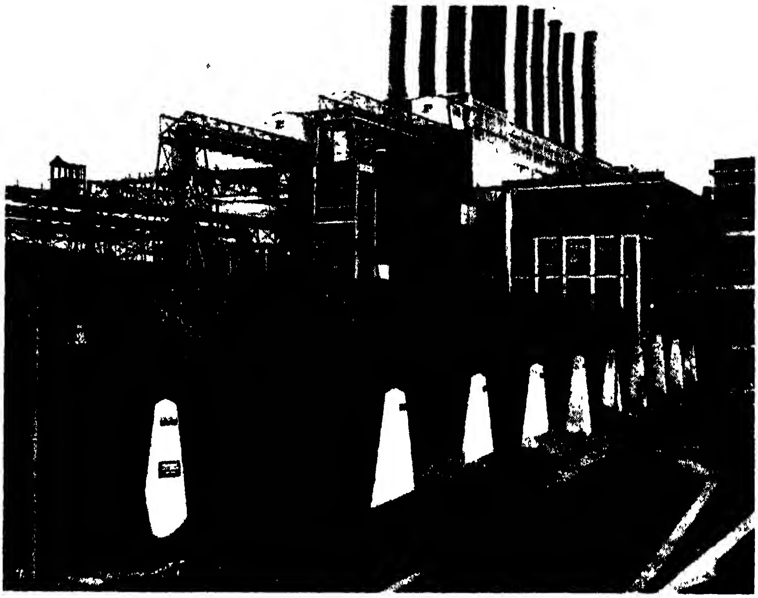


FIG. 102. Drag Scraper System at Barton Power Station handling Coal at 75 tons per hour on an average haul of 100 ft. Winch fitted with 50 H.P. motor and remote control gear. Capacity of store, 27,000 tons. Plant fitted with back posts of concrete construction. (International Combustion Ltd.)

considered available for daily demands, and a restricted area of less than half the total area can be worked. The average length of haul over this restricted area should not exceed 100 ft., thus obtaining a high-moving capacity in both motions. The outer area is held as a reserve store over which the rate of handling need not be high under normal working conditions. Rope wear is aggravated by the snatch at take-up of load, and as wet, consolidated and frozen coal piles have to be dealt with, any smoothing out of this initial kick may impair reclaiming operations. The inclusion of an hydraulic coupling between the motor and winch reduces the snatch on the rope.

Friction clutches are liable to damage if continuous slipping takes place. The hydraulic coupling provides a good alternative, and is completely automatic at all speeds. It is not suitable for drives requiring the maintenance of exact speed ratios, as its action depends upon the relative slip between the two shafts. For a given maximum input torque and speed, this coupling will apply the required output torque at the expense of a reduction in output speed, which may fall to zero without damage to the coupling or

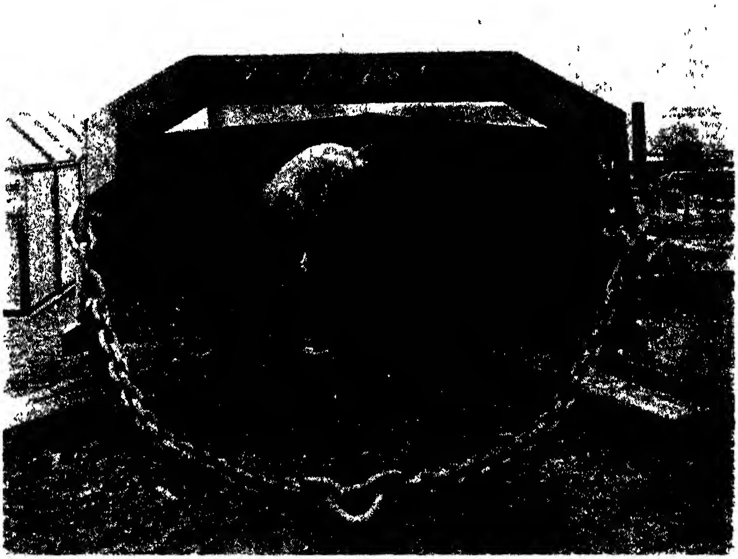


FIG. 103. Drag Scraper Bucket for Barking Power Station, handling 150 tons per hour (4 cubic yard bucket), on an average haul of 225 ft. Winch fitted with 200 H.P. motor. Capacity of store, 85,000 tons. Both winch and tail car fitted with remote control gear. (International Combustion Ltd.)

overloading of the motor. The rate of response is still hardly up to that of electromagnetic couplings. Nevertheless, there is complete enclosure ; less noise, and greater simplicity of controls.

It has been suggested that a life of 12,000 tons for the inhaul rope can be expected although this is found to vary. Some users have removed the digging teeth and fitted shock absorbers in an endeavour to overcome excessive cable wear and breakage. This has not always resulted in any marked improvement and the teeth have had to be replaced due to the coal sticking, freezing and channelling.

Much remains to be done in the design of this simple but effective

plant and no doubt experience gained on present installations will be of use to manufacturers. It appears to be a question of balancing wear and tear on cables against the capital cost of equipment provided and assume this to be the best solution. The coal stored by this method is more generally mixed and compressed than when the heaps are formed by depositing the coal from a chute, grab or conveyor. Segregation takes place when the coal rolls down a slope as the lumpy coal rolls to the bottom, leaving the fine material on top, which is conducive to spontaneous combustion. Figs. 102 and 103 give typical details.

Conveyor Storage. Storage made by conveyor is a moderate-size working heap and seldom remains untouched for long periods. If this is so, it is justifiable to forget the heating danger which may be caused by coning and segregation. The storing belt conveyor can be made reversible and used for reclaiming, a travelling hopper with feeder being fed by grab.

Telpher Storage. The telpher is of the man-trolley monorail type, and may be used for unloading colliers, discharging to storage or bunkers and reclaiming from storage to bunkers. The storage is limited since the line of the grab is fixed, and if storage is on the ground the telpher can only recover about half the amount stored, the remainder having to be brought within reach of the grab. Since the telpher stores in a straight line, it cones and segregates the coal. It is possible to increase storage and reclamation by including a traversing bridge or transporter and using a top-rail telpherage system. A branch track at right angles to the main track is provided with a running switch, and the complete curve and branch track is carried by a girder which spans the coal store. This method cannot be applied to a bottom flange system owing to the running switch.

Underwater Storage. This method has been adopted wherever site conditions permitted. The coal does not deteriorate under water, is free from the fire hazard and also reduces the danger from incendiary bombs, which now have to be reckoned with in aerial warfare. Drag scraper, transporter and telpher handling can be applied to this method of storage. Disadvantages are deterioration of grabs and scraper equipments.

Miscellaneous. Other equipments which have proved satisfactory for stacking and reclaiming large quantities of coal on open ground are: (1) portable inclined belt conveyor; (2) portable chain and bucket elevator; (3) mechanical shovel (scoop, bucket or bulldozer).

Electrical Equipment. The electrical equipment should be of robust design and construction and suitable in all respects for all conditions of service. Electrical equipment is generally very reliable and also scores on economic grounds and flexibility. The motors should be liberally rated with enclosures to suit working conditions. Speaking generally, totally enclosed motors are usually adopted for all services. In view of the prevalence of dust and dirt, motors of the totally enclosed fan-cooled type are favoured. Cooling is assisted by an external fan which forces air over the shell of the machine. With this form of construction it is impossible for dust, dirt or moisture to gain access to the interior of the machine, while the system of forced ventilation adopted enables the overall size of each motor to be reduced considerably as compared with ordinary totally enclosed machines.

The contactor gear, switch fuse boards, limit switches, controllers, etc., should be placed in accessible positions to facilitate inspection and maintenance. Where necessary this apparatus should be dust and weatherproof.

The various items of plant are interlocked and work in some predetermined sequence. Emergency stopping devices are included throughout the system, and it is usual to provide "stop" pushes at regular intervals of 30 to 40 ft. along the length of a conveyor walkway. Probably the simplest case of interlocking is where an elevator is working with a conveyor. The electrical connections are arranged so that it is impossible to start an elevator until the conveyor is in service. Similar arrangements would be necessary for a feeder supplying a conveyor or a skip hoist.

Although many interlocking schemes are now giving satisfactory service, it is impossible to eliminate the human element entirely. The operation of a wagon tippler is controlled by a manually operated controller in both forward and reverse directions. The equipment is fitted with a limit switch that automatically stops the hoist on reaching either the top or bottom positions.

With skip hoist or bucket elevator installations, where two hoisting units discharge into a common top hopper feeding two conveyors, interlocking arrangements are incorporated. Should one conveyor fail when both hoisting units are working, the top hopper would overflow unless the attendant stopped one hoist. The inclusion of a change-over switch makes it possible to run either conveyor with either hoisting unit, and appears to meet all requirements.

General Data. A number of installations are given for the purpose of reference :—

Example "A"

Wagon Tipplers

Number installed	Two.
Type	Side discharge fitted with weighing machine.
Size of wagons	8 to 20 ton standard coal wagons.
Number of wagons per hour	10.
Minimum capacity	80 tons of coal per hour each.
Type of weigher	Fitted with printing steel yard.
Motor data	25 B.H.P., 480 r.p.m., T.E.S.R. 1 hour rating.

Skip Hoists

Number installed	Two.
Type	Counter balance.
Capacity	80 tons per hour each.
Capacity of skip	6,000 lb. each.
Time for complete cycle	2 minutes.
Number of trips per hour	30.
Speed of hoist	250 ft. per minute.
Motor data	45 B.H.P., 730 r.p.m., T.E.S.R. continuous rating.

Conveyors

Number installed	Two.
Type	Belt.
Length	270 ft.
Size	24 in. wide 5 × 3 ply.
Material	Rubber and canvas.
Thickness of rubber	$\frac{1}{8}$ in. carrying side, $\frac{1}{16}$ in. return side.
Total thickness	$\frac{7}{16}$ in. approx.
Speed	200 ft. per minute.
Capacity	80 tons per hour each.
Materials handled	Boiler house coal.
Tripper speed	20 ft. per minute.
Motor data	10 B.H.P., 730 r.p.m., T.E.S.R. continuous rating (brush lifting gear).
Head pulley	24 in. diameter } All 26 in. face, cast iron.
Tail ,,	20 ,,
Snub ,,	12 ,,
Bend ,,	15 ,,
Tripper pulleys	24 ,,
Troughing idlers	5 pulley type at 4 ft. centres (closer pitch at feed points).
Return idlers	Single pulley, at 10 ft. centres.

Feeders

Number installed	Two.
Type	Rotary table.

Speed of table . . .	20 r.p.m.
Capacity of table . .	80 tons of coal per hour each.
Diameter of table . .	5 ft. 6 in.
Motor data . . .	10 B.H.P., 730 r.p.m., T.E.S.C. continuous rating.

Receiving Hopper

Type	Reinforced concrete.
Capacity . . .	42 tons.

Example "B"

Wagon Tipplers

Number installed . .	Two.
Average capacity . .	140 tons of coal per hour each (data not given, as example "A").

Feeders

Number installed . .	Two.
Type	Jigging.
Capacity . . .	140 tons per hour each.
Motor data . . .	5 B.H.P., 750 r.p.m., T.E.S.C. continuous rating.

Conveyors

Number installed . .	One.
Type	Belt.
Length	445 ft.
Size	24 in. wide, 4 ply.
Material . . .	Rubber and canvas.
Speed	420 ft. per minute.
Capacity . . .	140 tons per hour.
Motor data . . .	10 B.H.P., 720 r.p.m., T.E.S.R. continuous rating.

Example "C"

Elevators

Number installed . .	Two.
Type . . .	Bucket (small coal).
Material . . .	Heavy malleable iron.
Length	110 ft. centres.
Number of buckets . .	114.
Speed	120 ft. per minute.
Capacity . . .	30 tons per hour.
Motor data . .	15 B.H.P., 710 r.p.m., T.E.S.R. continuous rating.

Conveyor

Number installed . .	One.
Type	Belt.
Length	190 ft.

Size	20 in. wide, 4 ply.
Material	Rubber and canvas.
Thickness of rubber	$\frac{1}{8}$ in. top, $\frac{1}{32}$ in. back.
Speed	200 ft. per minute.
Capacity	30 tons per hour.
Motor data	$7\frac{1}{2}$ B.H.P., 960 r.p.m., S.P.S.C. continuous rating.
Head pulley	20 in. diameter (All 22 in. wide.)
Tail ,,	20 ,, (All 22 in. wide.)
Snub ,,	9 ,, (All 22 in. wide.)
Troughing idlers	3 pulley type.
Return idlers	Single pulley.

Receiving Hopper

Number installed	Two.
Type	Reinforced concrete M.S. plate lining.
Capacity	10 tons each.

Drag Scraper (small area, 3,500 tons)

Capacity	70 tons per hour.
Journeys	78 per hour.
Time Out and In	46 seconds.
Speed of haul	7·35 ft. per second.
Distance out and in	360 ft.
Motor data	60 B.H.P., 970 r.p.m.

Example " D "

Suction Plant

Reciprocating vacuum pump	175 B.H.P.
Free air	4,500 cub. ft. per min.
Vacuum	9 12 in. Hg.
Pipes	7 in. dia.
Capacity	90 tons per hour.

Estimation of Plant Capacity. A boiler house has eight boilers of 187,500 lb. per hour M.C.R.

Total steam available = 8 × 187,500 lb. per hour.

Assuming average steam per unit generated = 10 lb.

$$\text{Total units generated per hour} = \frac{8 \times 187{,}500}{10}.$$

Assuming average coal consumption per unit generated = 1·2 lb.

$$\text{Coal used per hour} = \frac{8 \times 187{,}500 \times 1{\cdot}2}{10 \times 2{,}240}$$
$$= 80 \text{ tons.}$$

Alternatively the coal used can be estimated as follows :—

Water per lb. of coal of 11,000 B.Th.U. at 86 per cent. efficiency :

$$W = \frac{C.E.}{f_e L.} \quad \text{where} \quad C = \text{calorific value of fuel}$$

$$E = \text{efficiency of boiler.}$$

$$= \frac{11{,}000 \times 0{\cdot}86}{1{\cdot}25 \times 970{\cdot}7} \qquad f_e = \text{factor of evaporation.}$$

$$L = \text{Latent heat of steam at } 212^\circ\,\text{F.}$$

$$= 7{\cdot}8 \text{ lb.}$$

$$\text{Total steam available} = 8 \times 187{,}500 \text{ lb. per hour}$$

$$\therefore \text{ coal used per hour} = \frac{8 \times 187{,}500}{7{\cdot}8 \times 2{,}240}$$

$$= 86 \text{ tons.}$$

It is quite unlikely that all boilers will be working together or even at the M.C.R. output. It is reasonable to assume that six boilers would work together, in which case 60 tons per hour would be required. It is always desirable to have sufficient capacity in hand to allow for the varying conditions of operation and classes of coal used.

The actual capacities of coal-handling plants usually fall much below the designed figures, as will be observed from the following data :—

	Actual Operating Conditions	Test Results
Coal to Bunkers		
Maximum tons per hour (good coal) . .	80	80
Minimum tons per hour (wet coal) . .	40	
Average tons per hour (average coal) .	60	
Coal to Store		
Maximum tons per hour	60	80
Average tons per hour	50	
Reclamation from Store to Bunkers		
Maximum tons per hour (good coal) .	60	80
Minimum tons per hour (wet coal) . .	25	
Average tons per hour (average coal) .	45	

Water-borne Coal

Average capacity

Colliers up to 2,000 tons .	50 per cent. of maximum capacity
Colliers 2,000 to 5,000 tons.	60 ,, ,, ,,
Colliers 5,000 tons and over	70 ,, ,, ,,

Maximum capacity is possible at high tide and full cargo.

In many cases duplicate items of plant are installed throughout, whereas in others only certain sections are duplicated.

The question of shift working must also be considered, and by duplicating handling plant it will be possible to meet the coal requirements much quicker with consequent saving in labour. For example, in one eight-hour shift with two conveyors each having a handling capacity of 80 tons per hour it is possible to meet the requirements of the boiler house under maximum steaming conditions for twenty-four hours.

CHAPTER VI

ASH-HANDLING PLANT

The disposal of ashes from a large-capacity power station is of some importance when it is realised that they represent from 10 to 20 per cent. of the coal used and may amount to more than 60,000 tons per annum. The problem of ash and dust handling and particularly the disposal, is one of the major points in station design. The ash plant should be located on the leeward side of the station so that dry ash is not blown or drawn into the buildings.

Where sea-borne coal is in use barges may be used for dumping ashes in the sea. Inland stations depend on building contractors for the disposal of a large proportion of the ashes, although waste land sites may be reserved for this purpose. Land for ash tipping is necessary unless there is a large demand for ashes for building, roadmaking and similar purposes. Disused quarries within reasonable distance of the station are worth acquiring as they are usually capable of catering for the ash requirements over a number of years. Ponds with deep embankments may also be constructed, and when capacity is reached they can be covered with soil and seeded with grass.

Ash disposal is a problem, even if ingenious methods are devised to clear the boiler residue out of the building. Whatever plant is adopted it should have a minimum number of units of robust construction with a view to reducing maintenance and running charges to minimum. The ever-increasing capacities of boiler units together with their ability to use low-grade coal have been responsible for the development of numerous systems of ash handling. The fundamental problems in ash handling are dust nuisance, hot materials, abrasive properties, poisonous gases and corrosive acids. It is preferable to quench the ashes and some of the advantages of water quenching are : the sudden quenching of ash tends to disintegrate large clinker and reduce it to more manageable proportions ; it reduces the ash to a dustless condition and the water is used as a seal to prevent uncontrolled air entering the boiler undergoing ashing and so upsetting combustion conditions.

Ash from retort stokers is comparatively cold when it leaves the pit and the advantage of disintegration is not obtained and frequent crushing is desirable. If continuous crushing were carried

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out the ash would be hot and disintegration would take place preventing choking of the sluiceway, but serious trouble would be experienced on the crushers and shafts. A head of ash should be maintained above the crushers, and grids under the ash hoppers serve no useful purpose and need not be fitted. Whether in a dry state or carried in water, any parts of conveying equipment which are in contact and move in the ashes or in a mixture of ashes and water are subject to excessive wear. The simplest and by far the best method of ash removal is to arrange for railway or road wagons to travel immediately below the boiler ash outlets, but this necessitates a higher boiler house basement and quenching sprays in hoppers. Alternatively, hopper wagons may be used. Whatever system of handling is installed removal of ashes from the boiler outlets and basement in case of failure of the main system must be allowed for. Narrow-gauge ash wagons running alongside the ash outlets are suitable. The ashes have to be removed from the boilers and transported direct to a disposal dump or held in storage until disposal facilities are available. To carry out these operations various types of equipment have been used, some of which are ash wagons, skips on runways, aerial ropeways, scraper conveyors, water-sluicing, pneumatic suction, belt conveyors, etc. The method chosen will depend to a great extent on the site and other local conditions. The efficient handling of ashes is a matter of utmost importance in a station running at high load factor and burning any considerable tonnage of coal, especially when it contains a high percentage of ash.

The fact that power stations are likely to continue to run at high load factors and burn large quantities of low-grade coal, having a high percentage of ash, demands that close attention should be paid to the ash-handling plant if reliable and economic operation is to be maintained. For any ash-handling plant it is generally recognised that the principal requirements are :—

(1) The plant should be able to handle large clinkers, boiler refuse, soot, dust, etc., with the minimum of attention from operators.

(2) The ever-present feature of abrasion should be rendered ineffective by the adoption of plant and equipment designed and constructed in such a manner that long uninterrupted periods of operation can be obtained with little attention.

(3) The plant should deal effectively with hot and wet ashes, and operate with but little noise, and, above all, keep the dust nuisance within desirable limits.

(4) The operating and maintenance charges should be kept to a minimum, and in this respect experience shows that the layout of the plant plays a considerable part in effecting savings. Reasonable facilities for access during

operation and maintenance are essential if this is to be achieved and the continued interest of the personnel—a most important consideration—is to be maintained.

(5) The system adopted should under all conditions of operation lend itself to the ready disposal of the ash from the site.

(6) The plant should have a high rate of handling in order to deal adequately with any sudden change in boiler operating conditions, and consume as little power as possible.

(7) The ultimate station capacity should be considered in the early stages of design, and the ash plant employed should permit of extension to meet all future needs.

In practice the characteristics of boiler ash vary over very wide limits, and the production of large clinker is almost unavoidable when poor classes of coal are burned. The ash is also found to vary according to the method of firing employed. Troubles may be experienced with any of the firing systems now in use, depending on the classes of coal fired and the combustion conditions obtaining. The thermal, chemical, and physical characteristics all play their part in the resultant ash formation, and no hard-and-fast rules can be made which will apply to all or any operating conditions likely to be met with in practice. In the case of pulverised fuel, it should be mentioned that some 60 to 85 per cent. of the total ash content appears as dust in the grit arresters and hoppers, and can, therefore, be separated from the ash system if desired. It has been the general practice to discharge the flue dust and riddlings into the sluicing system, but experience indicates that this grit was responsible for the majority of the wear which took place on the piping and more usual cast-iron pumps. These grits or fines do not settle out in the sump, and in pulverised fuel plants they appear to be made up of hollow spheres which are able to float, and may even extend to a depth of some 2 ft. under the water surface. This sump water is nearly always in a turbulent state, a condition which does not assist settling. Difficulties have been experienced with the grits that do settle, due to their causing the bulk of the ash in the sump to set hard after a few hours. This makes the task of reclamation by grab more difficult.

During very frosty weather it may be necessary to dry a proportion of the ash before disposal. Holding up of ash in the receiving bunkers may be caused by freezing up solid in which case steam may have to be applied to free it. Space should be left between the sump and bunkers to allow wagons or road vehicles to be filled direct from the grab.

In years to come there may be no necessity to handle ashes if

pit. The centrifugal pumps have their suctions arranged tangentially from this pit. The function of the swirl pit is to maintain the ash in suspension in the water thus enabling the pumps to handle it satisfactorily. These pumps are full bore and discharge the ash and water either to temporary storage bunkers or waste land. Where waste land is available it provides a convenient means for ash disposal but a constant supply of make-up water is required for sluicing. A tapping off the condenser circulating water system may be used for this purpose.

When ashes are stored in bunkers a closed system may be used

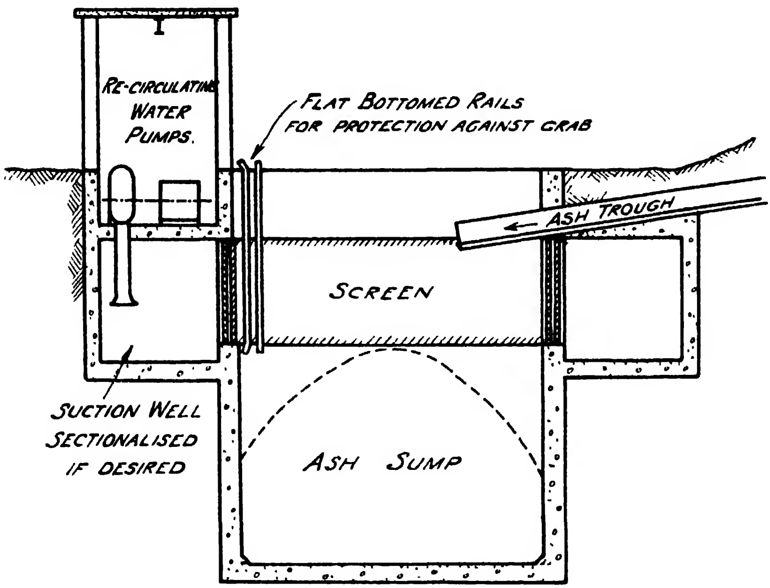


FIG. 105. Suggested Water Sluice Sump Layout.

in which the water is stored in an overflow tank. When the plant is started up the water is drained from the storage tank to the swirl pit where it is handled by the pumps and discharged to overhead ash bunkers. In these bunkers the water passes over a weir and gravitates to the heads of the sluice troughs. The bunkers are usually divided into a number of compartments each being filled alternately thus allowing a draining period before the ash is discharged. As the ash level rises in the bunker the displaced water is conveyed by way of overflow pipes to the overflow tank so that when the first compartment has filled with ash, water is available in the storage tank for use with the second compartment, and so on. These

bunkers are fitted with a special ash door which allows the water to drain off without opening the door. After a reasonable period of drainage the ash can be discharged direct into trucks, lorries or barges.

The high-pressure system has been chiefly used for pulverised fuel boilers. The hoppers below each boiler are fitted with water-jet nozzles at the top for quenching the accumulation of ashes and have sluicing nozzles at the bottom of the hopper. The ash is removed intermittently, since the hoppers are of large capacity, and the rate of ash removal is very high. When it is desired to empty a hopper the pumps are started which supply water to the sluicing nozzles in the hopper and culvert and the gate is then opened. The ashes and water flow along the trough to a receiving sump or whirl pit, the water being re-circulated as required. The ashes or slurry may then be pumped to overhead bunkers, ash dump or barge. Alternatives are to employ a grab transporter or telpher plant.

In the low-pressure system the water is re-circulated continuously. The continuous water-sluicing system has lower power costs, is more flexible, dispenses with dust troubles, and hot clinker on falling into cold water tends to be disintegrated.

With water quantities and power requirements it is difficult to make a fair comparison without detailed particulars of the two types of plants. Generally it would appear that while the quantity of water required for low-pressure sluicing was two to three times that for an equivalent high-pressure plant, the exact opposite would be the case for the maximum power required to drive the sluice pumps. This high power requirement was sometimes considered a disadvantage of the high-pressure system, but apart from the fact that it enabled a high concentration to be handled and reduced the danger of choking the sluice, it should be considered from the points of view of (*a*) that, as all sluiceway booster nozzles upstream of the boiler being ashed were turned off, the average power consumption was most likely to be only two-thirds of the maximum ; and (*b*) that the high rate of handling enabled the plant to be operated intermittently for, say, one-quarter to one-sixth of the time required by the continuous low-pressure system. Therefore, the power units per ton of ash handled by a high-pressure system would appear to be one-third to one-half of those required by an equivalent low-pressure system. Some of the features requiring attention for the satisfactory operation of water-sluicing systems are :

(1) The employment of regular and experienced operatives. Although those systems are comparatively simple and easy to manage, a knowledge

of the varying conditions—which can only be gained by experience—is indispensable if repairs and maintenance charges and plant outages are to be kept at a minimum. Wear and tear are inevitable in the best of plants, but the watchful attendant can materially assist by bringing anticipated failures or shortcomings to the notice of his engineer.

(2) Maintenance of correct ash level in the receiving sump. Here again attention to detail by operatives will avoid interruptions due to shortage of water to the pumps. The ash level should be as low as possible to ensure the maximum volume of water in the sump.

(3) The sump should be as large as possible, with due regard to the cost of construction, for there should always be an adequate supply of water in the troughs.

(4) Due to the varying nature of the ash likely to be met in practice, it is well-nigh impossible to provide a trough system which will be entirely trouble-free, particularly with respect to choking. Choking can, however, be reduced to a minimum by providing straight runs of sluicing troughs with reasonable fall, together with an adequate supply of water at a reasonably high velocity. In fact, the velocity of the water in the sluices should be as high as practicable, for it is found that velocity is of greater importance than quantity. Where bends are unavoidable, it may be necessary to augment the velocity by including water jets.

(5) The trough linings should be maintained in good order to facilitate the flow of water-borne ash. Generally, it is observed that the ash flows much more freely when the linings have worn smooth.

Pneumatic Suction System. This consists of a suction pipe from the boiler ash outlets to a crusher, then to a bunker outside the boiler house and continued on to the exhauster *viâ* a filter. The air velocity accelerates, floats and maintains in suspension the largest particle of material taken into the suction system. The ashes accumulate until they are passed through a crusher to ensure being carried off to the storage bunker. Valves and connections are provided on the hoppers and suction pipe (Fig. 106).

The crusher is mounted on narrow-gauge rails above the suction pipe and evacuation is effected by placing it between the corresponding hopper valve and the connection below. The pipe connections, when not in use, are closed by cover-plates so that the hopper undergoing evacuation obtains full benefit of the suction.

The inlet of the suction pipe which is open to atmosphere, has a slide valve and vacuum guage fitted.

Sharp bends should be avoided to reduce wear, and rising ash pipes should have a gradual slope rather than a vertical rise. A powerful slow-speed exhauster and an expensive motor or the use of reduction gears and drive are necessary. The dust-laden air is pulled through a wet-air filter by the exhauster to protect its vanes. The disadvantages of this method are: large amount of wear on

pipework, labour and maintenance charges are high, and it is rather dirty and noisy.

Belt Conveyors. The conveyor used for coal handling is suitable for ashes after they have been quenched. One form embodies a tank containing water in which is immersed a paddle wheel set at an angle to the horizontal. On revolving the paddle wheel, ashes delivered to the tank are lifted to the top edge of the tank and discharged to the belt conveyor. The ash outlets on the boiler hoppers are sealed in this water tank and individual drives are fitted. This method provides for continuous and automatic removal

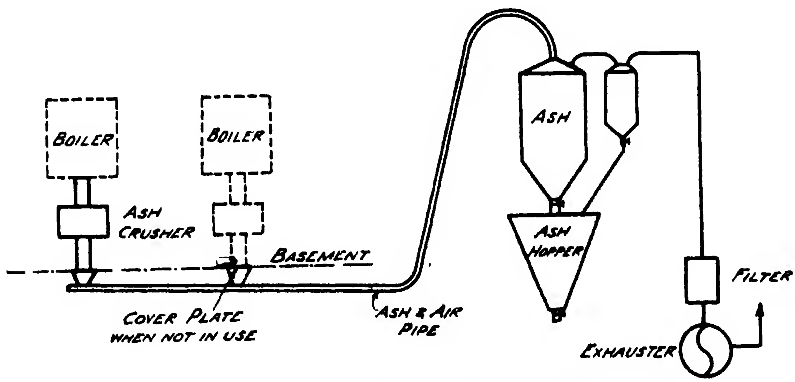


FIG. 106. Pneumatic Ash Suction Plant.

of ashes and reduces labour charges. Another type (Fig. 107) consists of a belt which is formed into a trough shape by means of guide wheels on the carrying side and travels in a cast-iron trough containing water. The ashes drop from the hoppers through extension chutes and are quenched before coming into contact with the surface of the carrying belt. As the carrying side of the belt is submerged the belt becomes water-borne, thereby reducing the power required. The discharge is continuous and driving with a belt speed of about 1 ft. per minute it will deliver up to 3 tons of ash per hour. This figure can be increased by raising the belt speed. It is claimed that the life of a belt working under normal conditions exceeds five years.

A rise of only 20° or so is practicable unless an attendant is kept at approach to rise to assist the ash up incline. It is desirable to wash underside of belt to prevent surface damage when passing over end rollers. Side rollers are necessary to prevent the belt wandering.

Belt conveyors and their ancillary equipment are discussed under coal-handling plant.

Ash Troughs. The troughs are placed beneath the ash hopper outlets and run the entire length of the boiler house basement. They may be formed above or below basement lèvel and are connected to a central sump or whirl pit outside the boiler house. The troughs may take the ash, riddlings and flue dust although the latter are sometimes kept separate until the main trough is

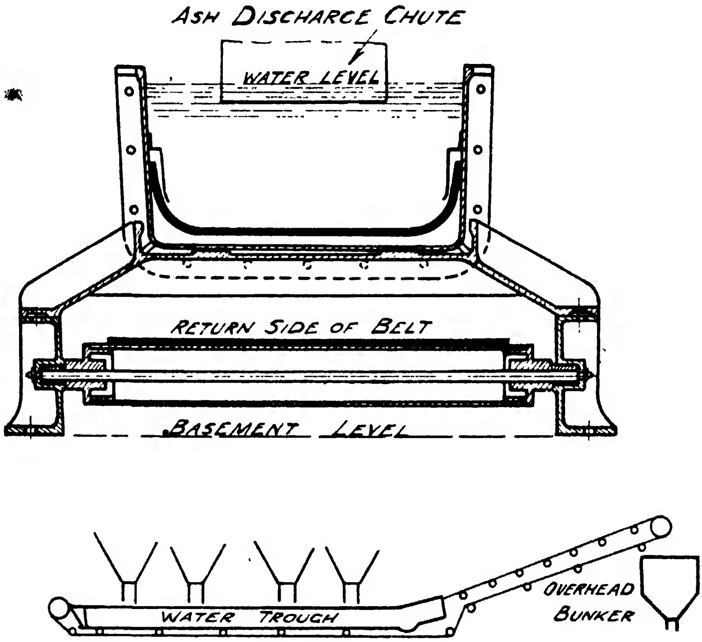


FIG. 107. Submerged Ash Conveyor. (John Thompson Ltd.)

reached. Owing to the very abrasive nature of ash, the troughs are provided with renewable liners of semi-circular section made from special cast iron designed to resist erosion and abrasion. These liners are grouted into the concrete troughs, and when renewal is necessary it is not difficult to chip away and re-lay with new liners.

Altornatively, when the liners begin to show signs of wearing through on the bottom, renewable liners of larger section may be placed over the old liners. The new liners are grouted up and are easily removed should the need arise. It has been suggested that the inclusion of a $\frac{1}{8}$ in. rubber insertion between renewable liners will give at all times a non-turbulent flow. The liners are in lengths of

about 3 ft. and have lifting holes to facilitate handling. In some cases the liners are sprung into position against the sides of the rectangular concrete trough.

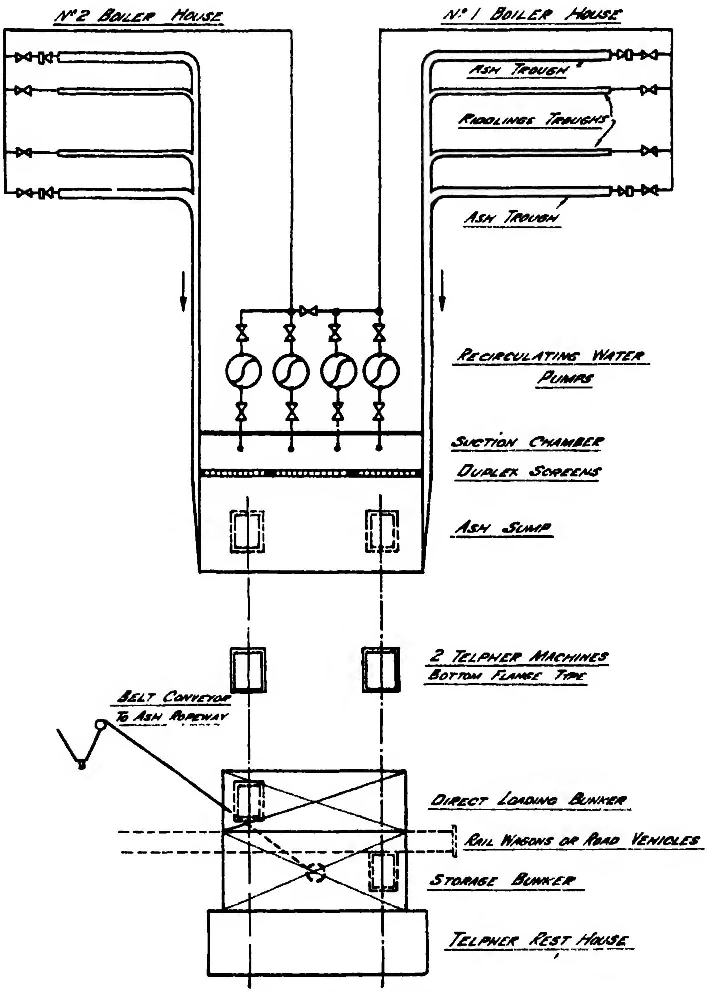


FIG. 108. Ash-handling Plant.

Tests carried out on various materials for trough liners for chain grate stokers give varying results and appear to depend on local conditions. Table 15 gives details of some materials.

TABLE 15. *Wear of Liners of Various Materials*

Material	Wear per 1,000 Hours in Use	Remarks
	In.	
Manganese bronze . .	0·017	
Common brass . . .	0·041–0·045	
Stoneware. . . .	0·043–0·056	
Gunmetal	0·045	
Chilled cast iron . .	0·047–0·077	
Nickel-chrome cast iron A .	0·049	2½ per cent. Ni, ½ „ „ Cr.
Nickel-chrome cast iron B .	0·054	25 per cent. Ni, 1 „ „ Cr.
Nickel-chrome cast iron C .	0·060	4½ per cent. Ni, 1½ „ „ Cr.
Cast iron	0·062	
Aluminium . . .	0·097	Ran 6,450 hours, followed by complete failure due to rapid wear.
Glass	0·104	Cracked after 2,000 hours.
Rubber	2·209	

The average range of the ash-sluicing water in this case was as follows :—

*p*H value, 7·0–7·5 ; SO_4 380–500 ; Cl, 220–270 ; dissolved solids, 920–1,130 (all parts per million).

Ash sump water contains the following constituents which affect the corrosion of cast iron : (1) dissolved oxygen, which was the most important factor ; (2) dissolved salts, particularly chlorides and sulphates ; (3) dissolved CO_2, which might confer slight acidity on the water and thereby stimulate corrosion. The first could be considered as the controlling factor, for without oxygen the electro-chemical action—which is the basis of almost all corrosion troubles—could not take place. Hard brick lined sluiceways have also been adopted and appear to have given fairly satisfactory service.

Where retort stokers have been used it has been found necessary to tile these troughs or as an alternative use granite sets. Ordinary and toughened glass have also been used, the former proving better.

The troughs inside the boiler house may be covered with chequer plate and should be reasonably air-tight. Pre-cast concrete slabs

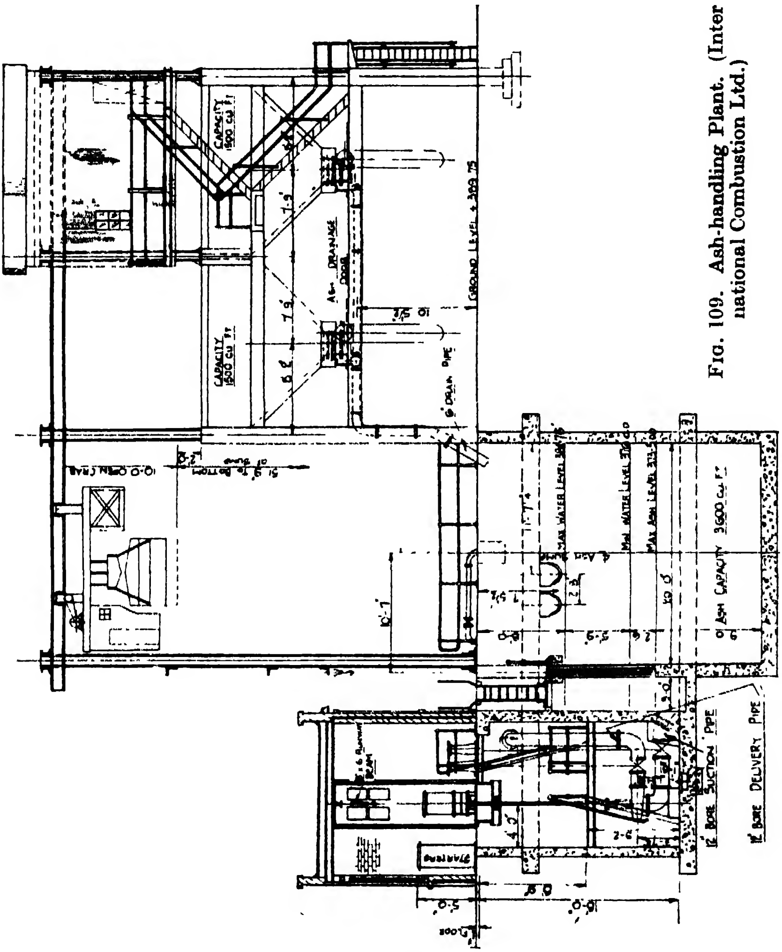


Fig. 109. Ash-handling Plant. (International Combustion Ltd.)

designed in accordance with traffic requirements, may be used outside. All troughs should have a suitable fall towards the sump. With the high-pressure system it is possible to run the sluice-way horizontally, which saves headroom or reduces excavation.

The provision of water jets at trough junctions and bends causes

a marked improvement in the handling capacity of the troughs. Where the supply pipe line passes nearby, it is usually convenient to provide one or more jets controlled by an isolating valve. These jets are simply tapered pieces of pipe—if a 6-in. main is in use, then the jet piece would taper from 6 in. down to about 2 in. diameter—and are connected to the branch pipe leading from the main line. Flat jets, curved to suit the trough radius, are also useful at junctions.

Air-sealing Doors. Care should be taken to prevent the ingress of air to the individual boiler ash hoppers by way of the sluice troughs. Air-sealing doors built into the troughs are provided between boilers which prevents air leaking from one boiler to the other at any time. When the sluice is operating the door is fully automatic and effects an air seal at any degree of opening. In one arrangement this door comprises a balance plate which floats just below the level of the water.

Such sealing plates do not appear to be necessary with retort-type stokers. Holding-up of ash appears to be a disadvantage of these doors.

Ash Sumps, Whirl Pits and Settling Pits. The sumps and pits are of reinforced concrete construction and hold the requisite quantity of ash. In fixing the size of ash sump the following data are useful: 1 ton of dry ashes = 50 cu. ft.; Minimum water level to give sufficient area through screen = 3 ft.; Allowance for rise in water level = $\frac{2}{3}$ of ash depth. This assumes that the ash will absorb $\frac{1}{3}$ by volume of the water displaced.

Example: assuming 8 hours storage and rate of delivery to sump 6 tons per hour

Total ash capacity	= 48 tons	
Ash volume	= 48 × 50	
	= 2,400 cu. ft.	
If diameter of sump = 15 ft.		
then depth of ashes = 13·5 ft.		
Allowance for water flow through screen		= 3 ft.
,, ,, rise in water ($\frac{2}{3}$)		= 9 ft.
Depth of Ash		= 13·5 ft.
		25·5

Total depth of sump below trough invert = 26 ft. approx.

The shape is usually circular, rectangular, or arranged to suit site conditions. Figs. 108 and 109 show typical layouts. The

usual practice is to construct the sump, suction pit and pump chamber as a complete unit. The design of ash sumps for grabbing requires care. The direction of entry of the sluices should be such that even distribution of the ash is obtained. The entry should not be directed against the screens or the amounts of "fines" recirculated will be great, as would also be the screen wear. Some installations have two independent suction pits and pump chambers. Duplex (one in use) screens running in cast-iron frames are incorporated in the partition wall between the sump and suction chamber. Various forms of screens built up of wedge sections or $\frac{3}{8}$-in. diameter mild steel rods at 1-in. centres are in use (Fig. 110). Baffle plates are sometimes fitted between the screens and the pump suctions. An overhead runway is provided to facilitate removal and cleaning of the screens. When a whirl pit is used the suctions of the slurry or ash pumps are taken into the pit and a dividing or whirling wall is included. The water is drawn off from the settling pits and returned to the slurry whirl pit for re-circulation. A certain amount of water would also be discharged to the drainage system. To compensate for any loss a make-up water system would be provided.

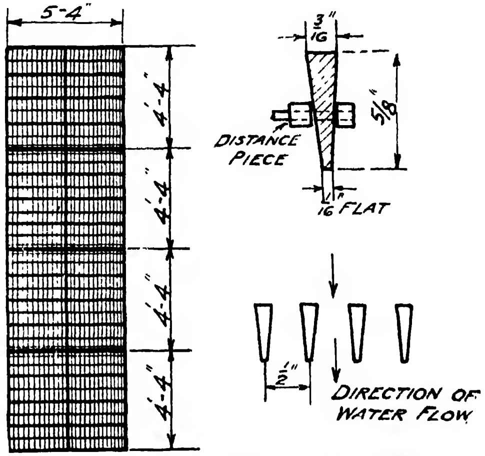


FIG. 110. Ash Sump Screen Details. (Mild Steel or Cast Iron.)

Receiving Bunkers. Two features deserving consideration in bunker design and construction are abrasion and corrosion. The resistance to the abrasive action of the ash sliding over the bunker faces is essential in all bunkers, whilst deterioration by corrosion is equally important. Corrosion may be both internal and external, particularly where the bunkers are situated in a fume-laden atmosphere or exposed to the weather. Receiving bunkers should be completely emptied at regular intervals, hosed down on the inside and then given a coat of bitumastic paint. The ash receiving bunkers may be of mild steel plate construction lined with concrete, or of reinforced construction throughout. Cast iron bunkers have also been

used for ash storage. In several cases extensive repairs have been necessary due to the concrete perishing and breaking away. Large sections of reinforcement become exposed and continuous making up is inevitable, which is rather costly. In one power station the bunkers, which are of reinforced concrete, were subject to rapid deterioration of the inside walls after a comparatively short period of service. Tests were made to determine the factors which were most likely to influence such deterioration where ash and water from a low-pressure ash-sluicing system were in contact with the concrete. Table 16 gives an analysis of the water usually re-circulating in the ash-sluicing system, from which it will be noted that the water may be alternatively alkaline or acid.

TABLE 16. *Analysis of Ash-Trough Water*

pH Value	Parts per Million		
	Sulphate SO_4	Chloride Cl	Dissolved Solids
—	320	—	—
8·0	380	64	800
6·5	560	11	1,350
4·5	780	27	1,100
6·0	760	28	1,600
8·0	438	36	700
7·5	503	18	600
6·5	621	—	950
3·0	1,000	—	1,900
3·0	1,539	—	2,400
3·0	1,670	—	2,400
8·0	370	—	600
3·0	—	—	2,500
3·0	—	—	1,750

Samples taken daily during January.

Table 17 gives an analysis of water taken from the drainings at the ash-bunker outlets, and also of water from the troughs. Generally the water drainings are alkaline, whilst samples drawn simultaneously from the ash-sluicing system are acid. It is reasonable to assume, therefore, that by reaction between water from the sluicing system—which is carried over with the telpher grab—and the materials of which the bunkers are constructed, the water becomes alkaline.

TABLE 17. *Analysis of Ash-Bunker Drainings and Ash-Trough Water*

Ash-bunker Drainings			Ash-trough Water	
*p*H Value	Sulphate SO_4	Chloride Cl.	*p*H Value	Sulphate SO_4
8·5	2,680	142	—	—
9·5	1,846	—	—	—
9·5	1,180	—	6·5	1,505
9·4	—	—	—	—
3·0	5,200	—	3·0	2,120
5·0	1,590	—	3·0	1,660
5·0	—	—	3·0	—
9·0	3,070	—	8·0	1,900
9·0	1,310	—	3·0	1,740

Samples taken daily during April.
Tests were carried out on filtered water samples.
Sulphates and chlorides expressed in parts per million.

A sample of water taken from the ash-receiving sump, showed the following :—

Analysis of Filtered Water	Parts per 100,000
Solids at 220° F.	656·20
Acidity calculated (H_2SO_4)	5·17
Silica (SiO_2)	0·80
Alumina (Al_2O_3)	1·60
Iron oxide (Fe_2O_3)	15·00
Calcium oxide (CaO_3)	52·30
Magnesium oxide (MgO_3)	21·20
Sodium oxide (NaO_3)	161·40
Chloride (Cl)	13·10
Sulphate (SO_3)	336·00

An independent authority gave the following proximate analysis :—

	Parts per million
Suspended solids	1,554
Total dissolved solids	6,858
Acidity (H_2SO_4)	58·8

Slight film of iron salts, slight globules of tarry matter, distinctly acid, partly free and due to hydrolysis of aluminium salts. Water corrosive owing to acidity and high salt-concentration (7,000 parts per million). The acid nature could be lessened by adding lime.

This approximate analysis compares favourably with the

previous sample results. The acidity was most probably due to the hydrolysis of ferric sulphate, and this would account for the separation of ferric hydrate from solution. The alumina-content is low. The dissolved content of this water is high at all times of operation, since hot solid matter is being dropped into a water system in continuous circulation. The actual solid-content varies with the solubility of the salts which constitute the coal ash and with the temperature of the water. The average temperature of the sump (February) water is 70° F. and of the drainings (March) 44° F.

The suggested addition of lime to the water system might lead to difficulties in the subsequent operation of the plant, because :—

(1) The quantity of lime added will vary with the degree of hydrolysis of ferric sulphate. Any excess of lime to produce a pH value higher than 7 will precipitate aluminium and ferric hydrates. A larger excess will precipitate magnesium salts.

(2) Ferric hydrate, a highly flocculent precipitate, will adhere to the screens and pumps, and may also produce local pitting owing to differential aeration. The running of solids in the screening plant may be retarded by the presence of ferric hydrate.

(3) The varying height of water—which is almost unavoidable—will make the control of lime addition difficult.

In order to investigate the cause of the change of the water (from acid to alkaline) drawn from the concrete bunker drainings, 3-in. test sample cubes of Earle's cement were made up and allowed to stand in :—

(*a*) 1 litre of solution pH = 3. Sulphuric acid in water.
(*b*) 1 ,, ,, ,, pH = 10. Potassium hydrate in water.

for a period of four days. It was found necessary to add more acid daily to (*a*), as the solution became alkaline. The cubes were examined and the solution was tested for its calcium content. The acid solution removed from the test-cube more than twenty times as much lime as the alkaline solution, and the surface of the test-cube was broken up after the immersion period. Tests were also made to determine the comparative resistance of ordinary concrete and tiles. A sample tile, made by the Accrington Tile Co., was used, and the samples under test were broken up and graded. The material which passed through a $\frac{1}{8}$-in. sieve and was retained on a $\frac{1}{16}$-in. sieve, was used, 50 grains of each being taken. The results showed that the tile material is more resistant to attack by acid solution than is ordinary concrete, and that in the alkaline solution it is slightly better. They also show that ordinary concrete is readily attacked by solutions of ash-sluicing water having a pH value of 3,

and that the deterioration of the bunkers may be attributed to attack of this nature. It was also observed that alkaline solutions attack concrete, but to a much lesser degree. Subsequent to these tests it was decided to line hoppers with Accrington tiles bedded in a special acid-resisting cement. After some five years' service it would appear that such tiles can be regarded as satisfactory for ash-bunkers. The tiles have resisted attack by acid ash water, with little or no deterioration of the tiles or bonding. The upper course of tiles in one hopper shows signs of deterioration at the edges, due

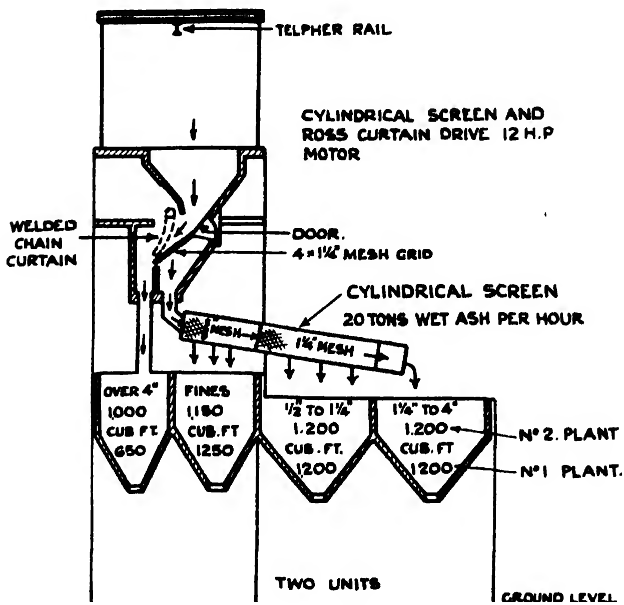


FIG. 111. Ash Grading Plant.

to the abrasive action produced by heavy clinkers falling from the upper receiving hoppers. No repairs or renewals have been carried out since the bunkers were tiled. Prior to lining with tiles, severe corrosion of the concrete lining occurred by the water draining from the ashes. Corrosion from this cause has been almost eliminated; further, it is observed that the tiles provide free running of the ashes when the bunkers are discharging, whereas formerly the fine ash tended to adhere and hold up on the rough concrete surfaces. Fig. 111 shows the layout of this particular ash disposal plant.

The tiles used in the lining are split paving tiles, 10 in. × 4½ in. × 3 in., each tile being split down the centre to make two tiles,

10 in. × $4\frac{1}{2}$ in. × $1\frac{1}{2}$ in. The concrete sides of the bunkers having been severely wasted due to attacks by acid, the concrete so affected was thoroughly cut away, and the remaining concrete was treated with Cement "Prodor" Solution. The whole of the bunkers were then lined with "Prodorphalte B," on which the tiles were bedded and grouted in White Cement "Prodor." The ash analysis taken over a considerable period was as follows :—

	Per cent.
Silica	37
Alumina	23
Iron	21
Sulphuric anhydride	3
Fluxes, etc.	16
	100

The density of ash varied and hard clinkers taken from an ungraded hopper gave an average figure of 169 lb. per cubic foot (wet). Dry weight of sample clinker selected 7·0 lb. and specific gravity 2·7. The weights of dry and wet ash vary considerably ; and so far as can be ascertained, wet ash figures of 55–75 lb. per cubic foot are usual.

A compromise has been made in which mild steel plates adequately stiffened and supported are used, the inside of the bunker being lined with hard-wearing concrete. An internal lining of 3 in. of granite concrete has been found satisfactory. The lower portions of the bunkers may have cast-iron sections which are renewable without disturbing the concrete lining. The outlets have cast-iron rack and pinion-operated doors of the self-draining type for draining off water in the bunker and returning same to the sump or drainage system.

The size and shape will depend upon the capacity and nature of ash to be stored. The most common is a single bunker into which the ash is discharged by means of a conveyor, elevator or grab. With small steel-plate bunkers served by elevators it is usual to have them totally enclosed. Although the single bunker is often used, much will depend upon the methods of ash disposal at the power station. Two-compartment bunkers have been adopted to suit local conditions. In one case a two-compartment bunker was used to store stoker ash in one compartment and fine riddlings and flue dust in the other. Where the handling plant necessitates the use of a feeder on the bunker outlet, it is usual to provide a double-compartment bunker. One compartment is in the form of a separate

bunker, and is only used for emergency service or when carrying out repairs to the main bunker. The small emergency compartment should be of such capacity to enable uninterrupted working of the ash plant to be maintained. It enables ash to be discharged by gravity into railway wagons or road vehicles below and not on to the feeder. The main compartment normally discharges on to the feeder, but alternative arrangements permit of filling wagons and vehicles direct.

Telpher with Grab. The telpher track is arranged so that the grab can serve the sump and possibly disposal bunkers. There are two types of telpher plants :—

(1) The Top Rail System in which a single running rail is fixed to the top flange of a steel joist which is fastened on one side of its web to supports. The bogies with two wheels in tandem are flexibly connected to the body of the machine by stiff hook-shaped links.

(2) The Bottom Flange System in which the track consists of a steel joist (or channels back to back) connected by its top flange to overhead supports. The four-wheeled bogies (or side-guided two-wheeled) run on the two inclined upper faces of the bottom flange.

The second system is generally cheaper and there is a saving in headroom.

With a straight track fixed bogies may be used, but on a curved track swivel bogies are employed.

The upper track is provided with renewable steel wearing strips machined to suit the angle of the flanges and screwed or bolted on. The strips should be reasonably thick and the fixing screws or bolts should not be too widely pitched or uneven running may be experienced due to the strips "rolling out" and buckling. The telpher has motions for hoisting and travelling, each driven by separate electric motors and operated from a cabin mounted on the telpher. A set of swivelling spring-loaded trolley collectors collect the current from the bare conductors.

A rest house gives cover to the telpher(s) when not in service. The layout of this house should permit complete inspection and overhaul of the machine(s). Opening doors in the floor will enable the grabs to be lowered to ground level and lifting gear for handling parts of the machine(s) is necessary. This system requires one operator per machine, power costs are relatively high but the maintenance charges are reasonable.

An access platform should be provided throughout the track length to enable driver to reach the rest house in the event of telpher failure.

Grab Transporters. An automatic transporter may be used for grabbing the ash from a sump.

At one station the grab discharges into an overhead hopper capable of holding 40 tons of wet ash. From this it is possible to load skips on an aerial ropeway or railway wagons. By making the grab entirely automatic the services of an operator are not required.

The normal cycle of the grab is as follows :—

The grab lowers into the sump and picks up its load of ashes, hoists to a short distance above water level, pauses for a few minutes to allow water to drain away from it, hoists to top, traverses to a point over the bunker and discharges. When fully open the grab will traverse out over the sump and again lower to take up a new load. This cycle of operation continues automatically until the stop button is pressed.

Pumps and Associated Equipment. The types of pumps to be used will depend on whether the high- or low-pressure sluicing systems are employed. With the former a high pressure re-circulating pump is required to give supply to the jet nozzles. A main ash or slurry pump, is used for pumping the ash from the sump to the dumping point which may be a settling pit, overhead bunker, barge or waste land. These pumps are subject to heavy wear and tear resulting in high maintenance and repair charges. Manganese steel impellers have been used with reasonable success, but it is difficult to machine and is expensive. A heat-treated alloy steel has also been used and proved fairly successful, and can be machined in the soft state before hardening. Heat-treated alloy cast iron is now used and has given good service, both for impellers and casings. With ash pumping the system is entirely enclosed and a telpher or grab operator is not required. It also affords greater flexibility in regard to positioning of ash bunkers which can quite often be some considerable distance from the boiler house.

For the low-pressure sluicing system re-circulating pumps are required. The pumps may be of the vertical spindle or horizontal types. The former are higher in first cost but occupy less building and floor space and do not require priming, whereas the horizontal type require a larger building and floor space and have to be placed in a pit to eliminate the necessity for priming. Both types are to be found in practice, although the vertical spindle appears to be generally favoured. In some cases the pumps and motors are mounted in the open without any protection from the weather. Experience indicates that horizontal pumps with steam or water air ejector priming are preferable particularly from a maintenance point of view. The pumps should be of robust construction to withstand the arduous working conditions. Mainten-

ance charges are usually of considerable magnitude under the best conditions, but unless careful thought is given to the selection of correct materials and facilities for access, these charges can become very excessive.

The renewal of pump impellers is a maintenance problem of importance and consideration should be given to the choice of material. For low-pressure re-circulating pumps, cast-steel impellers and nickel chrome have been used. Both cast steel and chilled cast iron impellers were employed in one station and had about the same life but the latter was only one quarter the cost of the former. Brass impellers have also been used and have given much better service than other materials. The casing may be of cast iron and of heavy construction or gun metal alloy. Figs. 112 to 116 give various ash pump particulars.

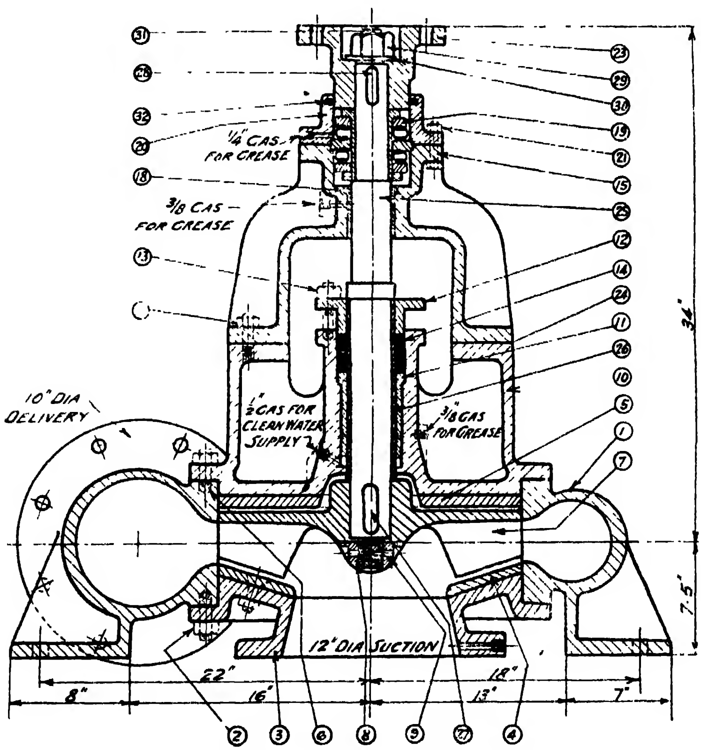


FIG. 112. Section of Open Type 10 in. Pump. (Gwynnes Ltd.)

Running clearance on underside of impeller—0·005 in.

Nut inside coupling screwed hard down holding thrust bearing and coupling firmly.

Adjustment by shims between top cover and arch bracket.

Fig. 112 key to references.

Ref.	Description.	Quantity.	Material.
1	Pump casing *	1	Gun metal
2	Studs and nuts	24	Mild steel
3	Suction cover *	1	Gun metal
4	Sideplate for do.* . . .	1	Gun metal
5	D.E. sideplate *	1	Gun metal
6	Bolts and nuts for do. . .	12	Stainless steel
7	Impeller *	1	Gun metal
8	Impeller nut	1	Stainless steel
9	Pin for do.	1	Stainless steel
10	Top cover	1	Cast iron
11	Bush for do.	1	Gun metal
12	Gland	1	Cast iron
13	Studs and nuts for do. . .	3	Mild steel
14	Gland packing	1 set	Hydraulic
15	Arch bracket	1	Cast iron
16	Studs and nuts for do. . .	4	Mild steel
17	Dowel pins	2	Mild steel
18	Arch bracket bush . . .	1	Gun metal
19	Double thrust bearing . .	1	Steel
20	Thrust housing in halves .	1	Cast iron
21	Bolts and nuts for do. . .	4	Mild steel
22	Fitted bolts and nuts . .	2	Mild steel
23	Pump half coupling . .	1	Cast iron
24	Arch bracket shims . . .	2	Sheet iron
25	Spindle	1	High tensile steel
26	Spindle sleeve	1	Case hardened steel
27	Impeller key	1	Key steel
28	Coupling key	1	Key steel
29	Coupling nut	1	Mild steel
30	Washer for do.	1	Mild steel
31	Split pin for do.	1	Mild steel
32	Grease washer	1	Felt.

* Items thus in gun metal alloy. 85 per cent. copper, 5 per cent. tin, 5 per cent. lead, 5 per cent. zinc.

The pumps are provided with branches to which a clean water flushing system is connected, one connection being at the stuffing box and the other at the eye of the impeller. This prevents the access of grit at the eye wearing point and keeps the spindle and impeller free from grit. The fine clearances between the impeller shrouds and the stationary casing are therefore sealed with clean water. In this way there is always a small leak of clean water inwards instead of having a leak outwards of gritty water past these fine clearances. It may be necessary to install a small pump to obtain the required head and quantity of cleaning water, and as the quantity may be considerable, this should be considered when comparing schemes.

The main pumps should be on the same longitudinal centre line and the suction and delivery valve-control pillars should also be

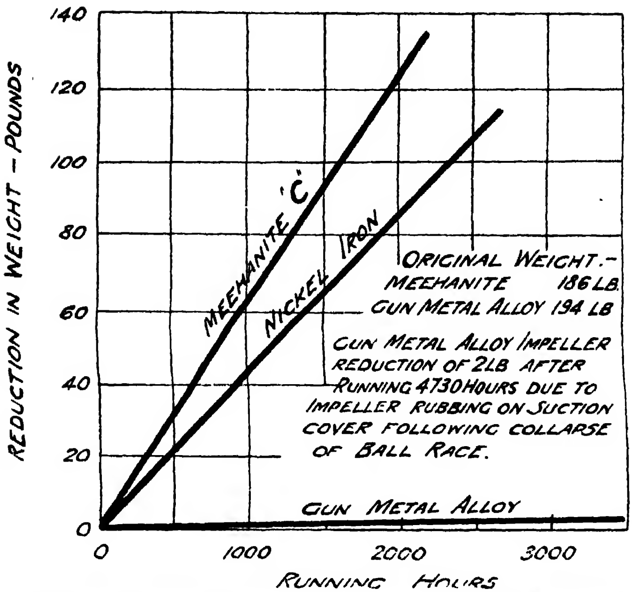


FIG. 113. Rates of Wear for Impellers of Different Materials.

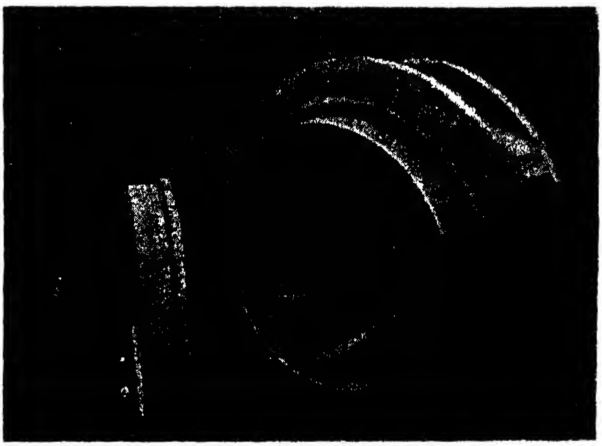


FIG. 114. Gun Metal Alloy Impeller, Nickel Iron Throat Liner and Mild Steel Shaft after 2,090 Hours Service.

Note: The wear on the impeller is due almost entirely to the failure of the thrust bearing which allowed the impeller to come into contact with the casing. On the top of the periphery the tool marks are still visible.

Analysis of impeller metal:

Copper	85 per cent.
Tin	5 ,, ,,
Lead	5 ,, ,,
Zinc	5 ,, ,,

kept in line, preferably near the wall. Universal couplings will make this practicable.

If the motors are controlled from individual starters these may

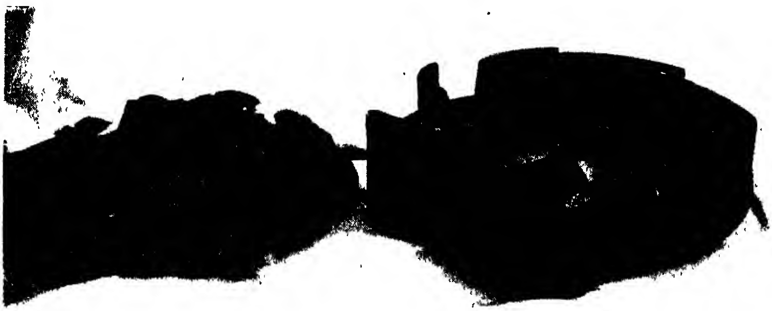


Fig. 115. Nickel Iron Impellers showing Wear on one after 4,900 Hours Service.

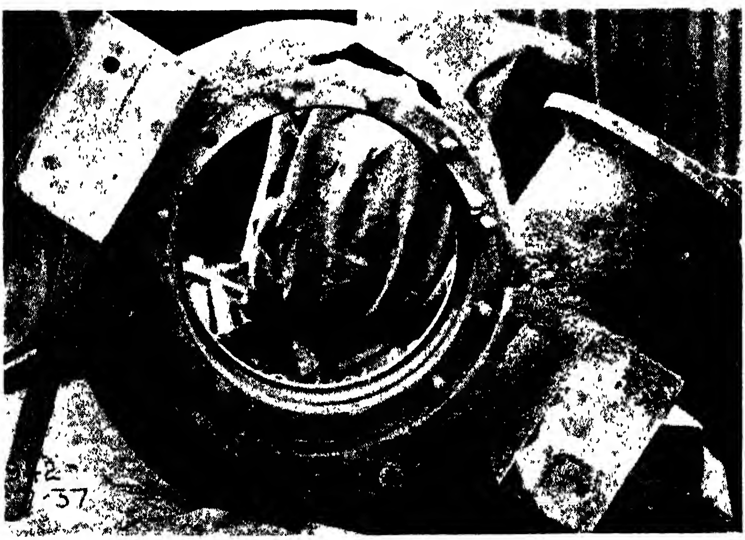


Fig. 116. Casing of Ash Sluicing Pump showing Abrasion in Waterway after some 4,500 Hours Service.

be placed in line near the corresponding valve-control pillars. The floor of the chamber may be of solid chequer plating or open grill flooring, the latter having the advantages of permitting a certain amount of light and ventilation to the pump pit below.

A runway joist and pulley block are useful for handling purposes. It would appear that some of the desirable conditions to secure trouble-free operation are :—

(1) Pumps should be constructed of gunmetal alloy in every part, with the exception of the shaft.

(2) Pumps should have a suction lift.

(3) An efficient clean water seal should be maintained on the pump gland and impeller clearance.

(4) Impellers should be of the open type to eliminate the out-of-balance with the shrouded type by holding ash between the vanes.

(5) Motors and pumps should be accessible with plenty of space for inspection and for such repairs as may be required.

In practice, it has been shown that wherever the water is turbulent, or changes direction (*i.e.*, in valves, bends, etc.), wear occurs, and it may be necessary to consider gun metal alloy wearing strips on bends and gun metal alloy valves in order to ensure a reduction in maintenance charges. The shrouded impeller, if properly sealed, will maintain its efficiency practically unimpaired throughout its life, whereas an unshrouded one could not be adequately sealed on the suction side so that clearance wear would be rapid, as also would be the falling off in efficiency.

The piping is of cast iron with flanges and rubber joints. The pipes for re-circulating water soon make-up with fine ash which sets very hard and cannot be removed so that replacement of pipes should be allowed for. Valves of the external-screw type are used. The internal screw is subjected to attack by fluid passing through the valve, and the ash content in the water justifies the external-screw type.

Piping laid underground should have at least 30 in. of cover or be laid in a concrete trench with heavy concrete cover slabs. Spigot and socket joints are used for underground piping.

Corrosion trouble due to acid was experienced when a *p*H value of 4 was recorded. The action on cast iron was worse than on steel.

Disposal of Ash. In some inland stations it has been found justifiable to install grading plants as it is sometimes possible to obtain good prices for graded ash.

The grading plant necessitates extra storage bunkers and space so that the price and demand should be carefully considered before proceeding with such equipment. Fig. 111 illustrates one grading plant.

Electrical Equipment. Pump motors may be of the drip-proof or totally enclosed air-cooled types. Other motors are of the latter

type. The control gear should be located as near as possible to the equipment with which it is associated, and should be accessible for maintenance and repairs.

General Data

Low-pressure Sluicing System

Ash Troughs

Slope.	1 in 60 straight, 1 in 40 curves.
Liners.	Cast iron (or chrome alloy C.I.), 9 in. radius: 1 in. thick (average), 3 ft. long.
Trough.	2 ft. 6 in. at top.

Riddlings Troughs

Slope.	Same as ash troughs.
Liners.	Cast iron, 6 in. radius, $\frac{3}{4}$ in. thick (average), 3 ft. long.
Trough.	1 ft. 6 in. at top.

Ash Sump

Type	Reinforced concrete.
Capacity	8,000 cubic ft. for ashes.
Depth	29 ft. from ground level.
Screens	$\frac{3}{8}$ in. wedge bar, mild steel.

Receiving Bunker

Type	Two compartment, mild steel plate with 3 in. concrete lining.
Total capacity	8,000 cubic ft. of ashes.

Pumps

Number	Four (two stand-by).
Type	Vertical.
Capacity of each pump	150,000 gallons per hour.
Total head	42 ft.
Rating of motor	55 B.H.P.
Speed	730 r.p.m.
Cleaning water required	20 to 25 gallons per minute.

Telpher Machines

Number	Two.
Type	Two motor, three rope grab.
Capacity of each	35 tons per hour of dry ash.
Time cycle	1·7 minutes.
Capacity of grab	55 to 68 cubic ft.
Speeds	130 ft. per minute—hoisting. 200 ft. per minute—lowering. 350 ft. per minute—travelling.

Belt Conveyor

Speed	150 ft. per minute.
Capacity . . .	35 tons per hour.
Feeder	Belt type—50 ft. per minute.
Materials . . .	Rubber and canvas.
Width	24 in. conveyor.
	30 in. feeder.

The average velocity of water in a trough is about 10 to 15 ft. per second. Abrasion is minimised with high velocity water which causes the ash to ride on the water instead of rolling or sliding along the bottom. Some 1,500 to 2,000 gallons of water per minute are required for a 9-in. radius trough handling from 10 to 15 tons of ash per hour on a slope of 1 to 65 or 70. For a 12-in. radius trough some 3,500 g.p.m. are required for handling pulverised fuel ash at about 40 to 60 tons per hour on a slope of 1 to 70. Allowance in water quantity should be made for bends and obstructions in the trough route.

High-pressure Sluicing System

High-pressure Re-circulating Pumps

Number . . .	One.
Type	Vertical.
Rating of motor . .	280 B.H.P.
Speed	1,465 r.p.m.

Ash Pump

Number . . .	One.
Type	Vertical.
Rating of motor . .	166/85 B.H.P.
Speed	1,465/965 r.p.m. (double wound).

The water pressure is usually about 100 lb. per square inch, the issuing velocity from the nozzles being approximately 130 ft. per second.

Estimation of Plant Capacity. Considering the example given under coal-handling plant where 86 tons of coal were required per hour and assuming limit of ash content in coal to be 15 per cent.

With 90 per cent. real ash this would form $15 \times \frac{100}{90} = 16{\cdot}7$ per cent. refuse to coal used.

Refuse from 86 tons of coal per hour $= 86 \times 0{\cdot}167$
$= 14{\cdot}3$ tons.

As a check one boiler unit of 200,000 lb. per hour rating gives about 1·5 tons of ash per hour.

$\therefore\ 1{\cdot}5 \times 8 = 12{\cdot}0$ tons per hour.

Total refuse (ash) for 8-hour shift = 14·3 × 8
= 115 tons (dry ash)

Wet ash weighs 75 lb. per cubic foot. (30 cu. ft. per ton).

Dry ash weighs 38 lb. per cubic foot.

A large quantity of water is lifted with the ash, but if the grab is held momentarily over the sump the bulk of the surplus water will drain off.

Hence weight of wet ash = 115 × 2
= 230—say 250 tons.

Capacity of sump to hold this quantity

$$= \frac{250 \times 2{,}240}{75} = 7{,}500 \text{ cubic feet.}$$

At the rate of 14·3 tons per hour it would take

$$\frac{230}{14 \cdot 3} = 16 \text{ hours to fill.}$$

If it is desirable that the work of emptying the sump be carried out in a shift of 8 hours, the capacity of the grabbing gear would be designed accordingly :—

Weight of wet ash to be reclaimed = 230 tons

Therefore capacity of grabbing gear to reclaim in 8 hours

$$= \frac{230}{8} = 28 \cdot 8 \text{ tons per hour (wet ash).}$$

To allow for stoppages, etc., it would be justifiable to work to 7 hours, in which case the capacity would be 34 tons per hour of wet ash (68 tons of dry ash). Two grabs each having a capacity of 34 tons per hour of dry ash would serve.

Operation and Maintenance Costs. Table 18 shows the costs of typical ash plants in this country and serves to indicate the general features of each system. Comparative costs are somewhat difficult to analyse due to the varying conditions of load factor, the type of plant and the site conditions generally.

Some idea of the costs chargeable to individual sections of plant for low pressure systems will be obtained from the following :—

Station 1

Repairs and Maintenance.	Cost per ton of ash handled. Pence.
Pumps and motors	12·0
Screening plant (fixed type)	2·0
Telpher	3·0
Troughs	2·2
Storage Bunkers (concrete)	0·8
	20·0

TABLE 18. *Ash-Handling Plant Costs*

(Year 1941)

Method of Handling	Drag Scraper in Water	Rubber Belt in Water	High Pressure Water Sluicing	Low Pressure Water Sluicing					Pneumatic Suction
Station	"A" (N.W.E.)	"B" (S.M.E.)	"C" (S.E.L.A.)	"D" (N.M.E.)	"E" (S.E.L.A.)	"F" (S.M.E.)	"G" (S.)	"H" (S.E.L.A.)	"J" (S.)
Repairs and maintenance	23	5	22	22	10	7	12	12	14
Operation (Handling and Disposal)	20	14	38	19	32	9	27	13 H 42 D	38
Total cost, pence per ton	43	19	60	41	42	16	39	67	52
kWh per ton handled	2	7		20	25	6	15	8	18
Remarks	Renewal of chain about 2 per annum at about 5*d.* per ton handled	Approx. 2 to 5 years life. All boilers ash continuously	Ash pumps	Stoker boilers generally ash continuously. Pulverised fuel generally ash once per day.					One boiler ashed at a time on each suction circuit.

NOTE.—N.W.E.—North West England. S.—Scotland. N.E.E.—North East England.
N.M.E.—North Midlands, England S.E.L.A.—South England London Area.
S.M.E.—South Midlands, England.

The total cost may be reduced by about 4*d.* to 1*s.* per ton from sale of ash.

Operation.

Handling and Disposal	18·0
Total cost per ton	38·0
Units (kWh) consumed per ton of ash handled . .	20·0

Station 2

Repairs and Maintenance.

Pumps and motors	2·5
Screens and Telpher	7·0
Troughs and Sump	2·0
	11·5

Operation.

Handling	12·0
Disposal	40·0
	63·5
Units (kWh) consumed per ton of ash handled . .	10·0

CHAPTER VII

BOILER PLANT

THE function of a boiler or steam generator is to convert water into steam at the required rate of evaporation and at the desired temperature and pressure to suit the turbine which it serves. It should do this safely, efficiently and economically, bearing in mind capital charges, depreciation, operation costs, etc.

The whole of the boiler plant should be designed, arranged and proportioned to operate under load conditions specified for long uninterrupted periods at a high efficiency with low operation and maintenance charges.

The number and capacities of boilers to be installed will depend upon the output of the turbo-alternators, whilst the number will also be governed to some extent by the degree of standby plant to be allowed and the maintenance required. Other factors to be considered are station load factor, site, transport facilities and quality of feedwater and fuel.

The trend in base load stations is to have one boiler per turbine for normal working with a reasonable allowance of boiler plant to cover maintenance, survey outages and emergency conditions. As an example, two 50 MW turbo-alternators each having a steam consumption of 480,000 lb. per hour, could be served by six units each having an economical rating of 160,000 lb. per hour, which would allow one boiler to be out of commission for overhaul. If a 200 to 400 MW station is contemplated it is possible to use individual boilers of approximately 300,000 to 500,000 lb. per hour maximum continuous rating.

With interconnection of electrical systems and station pipework it is possible to reduce the amount of spare plant and this should always be considered. Schemes met with in practice are:

(1) To provide one boiler per turbine. This has the advantage that it is cheapest, since the capital cost per unit of output decreases as the capacity increases. It assumes a high availability factor for the boiler, almost equal to that of the turbine. Spare plant will still be required to permit of inspections required by government and insurance regulations.

The lengths of steam and feed pipes are reduced and unit interconnections are avoided.

(2) To provide two boilers per turbine; the capacity of each boiler being such that with both boilers in commission they can steam the turbine up to its maximum continuous rating. The boilers would at this stage only be operating

at their normal economical rating. The boilers may steam the turbine up to 60 or 70 per cent. of its maximum continuous rating. The boilers are normally steamed together at an easy rating which improves their availability and at the same time a reasonable output can still be obtained from the turbine in the event of trouble on either boiler units.

(3) To have three boilers per turbine; the capacity of each boiler being such that two can steam the turbine up to its maximum continuous rating. This provides great flexibility of operation and ensures continuity of supply, but the capital cost is high.

Boiler plant is of two main classes, namely :—

(1) Stoker-fired boilers ; (2) Pulverised fuel boilers ; and, as will be noted later, each of these may be further subdivided. The boilers in both classes are of the water tube type, varying in design and construction to meet the system of coal combustion adopted.

The boiler units should have the highest possible efficiency, and probably the most important factors making this possible are :—

(1) Attention to design and construction of the boilers, their associated auxiliaries and apparatus, so that long working periods and high reliability are ensured.

(2) The adoption of very high capacity units.

(3) A consistent supply of the grade of coal for which they are designed.

(4) The layout and means provided to facilitate operation of all sections of the plant.

Layout of Boiler Plant. The layout and arrangement of boiler plant should meet the following requirements :—

(1) Occupy a minimum of space to keep the cost of buildings and land within economical limits. The design and arrangement of the boiler house and its details should be symmetrical, whilst awkward pipes and difficult passages should be avoided.

(2) All auxiliary plant should be kept as far as possible at one level so that control can be centralised.

(3) The principal components such as superheaters, economisers, air-heaters and draught plant should be arranged to give easy access for inspection and maintenance.

(4) Each boiler should be physically independent in so far that a faulty unit should in no way endanger its neighbours. Major repairs should be possible without affecting units in service.

(5) Although it is not possible to obtain the same degree of appearance as is usual in the turbine house, by careful arrangement of auxiliary plant, pipework, platforms, controls, instrument and motor control panels, a reasonably good-looking boiler house is possible.

(6) Adequate natural lighting throughout, artificial lighting being provided where necessary.

The layout of boiler plant in relation to the turbine house depends on site conditions. Two methods commonly used—in one

case the boilers are arranged in rows at right angles to the turbine house and in the other they are in a single row running parallel to it. The choice of one or the other will also depend upon the size and layout of turbines. The sizes of boilers adopted would appear to have (apart from other factors) resulted from the desire to have a boiler house running parallel to the turbine house. The layout of boilers and turbines affects the cost of pipework and buildings, whilst the former has a bearing on the coal and ash handling plants to be installed.

With either layout the boiler units can be arranged for operation from a central aisle or by placing them back to back from two side aisles.

The central operating aisle has the advantage that the operator can control the maximum number of boiler units from a central position by placing the control panels and essential controls at a common point. The operator's or stoker's duties are usually confined to the operating aisle, and the division of labour is such that one operator is responsible for two boiler units. In a boiler house having, say, four to six large units, a leading operator or stoker would be on shift in a supervisory capacity.

The central aisle layout at right angles to the turbine house permits of a maximum amount of natural light from the end gable, but artificial lighting fittings will be necessary. For stations over 100 MW capacity this layout necessitates more than one boiler house, which means that the houses are comparatively short in length. Natural lighting is included in the two side walls, giving adequate light between and at the rear of the boilers. To obtain the maximum amount of daylight for operation the back-to-back layout is adopted. The operating sides face the windows and the aisle between the two rows of boilers may be utilised for steam and feed pipes and the structure for supporting the chimneys. There are no regulations regarding natural lighting, a general rule is that the area of glazing in any wall should be 30 per cent. of the total wall area. Roof lights can be included to meet the requirements of the upper sections of the boiler units. In some boiler houses extensive use has been made of patent glazing, only those portions of the side walls at the rear of the boilers being covered with protected metal sheeting. The glass panels are reinforced with wire and are set in steel-core glazing bars of the lead-clothed type. All the steel parts are galvanised under the hot process before being entirely sheathed in jointless lead glazing covers.

The central aisle of a boiler house arranged parallel with the

turbine house is dark around the centre and artificial lighting is necessary at all times at the rear of the units adjoining the turbine house. With modern plant it is feasible to do without a partition wall between the boiler house and the turbine house and in some cases a glass panel construction has been used.

Type of Boiler. The water-tube boiler is now universally employed for power station service and consists of one or more groups of tubes suitably disposed about the furnace to absorb the available heat. This type of boiler originated from a desire for safety.

High-head radiant boilers have a rate of water circulation that is more than ten times that of their steaming capacity, compared with six to eight times for forced-circulation boilers. Natural circulation is in general use. It consists essentially of a water-cooled furnace and a superheater. By the time that the gases have finished passing through the superheater, their temperature is so little above saturation temperature of the boiler drum that there is little point in providing a large amount of convection heating surface. Practically all the heat transfer is carried out by direct radiation to the tubes of the furnace walls. The largest boilers (800–1,000 k.p.h.) under construction are of the Radiant type. In certain cases, the furnace dimensions would be so large in order to obtain the necessary tube surface that it has become desirable to resort to twin-furnace construction, with a centre wall of tubes to give the additional surface required and thus reduce the overall dimensions.

The process of steam generation can be divided into two separate and independent processes :—

(1) The liberation of the heat in the fuel.
(2) The absorption of the heat by the boiler.

This type of boiler has justified its adoption due to its high evaporation and heat transfer capacity which are made possible by the following :—

(1) A large heating surface is available by the use of a multiplicity of small tubes.

(2) Rapid but uniform circulation in the tubes.

(3) The furnace, being apart from the steam-raising surfaces, can be designed solely from considerations of combustion.

(4) Comparatively large ratio of heating surface to water volume provides flexibility in steam demand.

Boiler units of this type have proved reliable and efficient, and further, they permit of large output in reduced building space. Typical boilers are illustrated in Figs. 117 to 121.

Battersea Power Station.

Retorts 53 Tuyere Taylor Stokers (each equipped with double 26 in. Crusher Rolls).

'aporation	300,000 lb. per hour.
continuous evaporation	375,000 lb. per hour.
›oration	400,000 lb. per hour.
ssure	615 lb. per square inch.
ed steam temperature	910° F.
›r temperature	355° F.
ting surface	25,080 sq. ft.
er heating surface	8,910 sq. ft.
›r heating surface	24,192 sq. ft.
heating surface	128,400 sq. ft.
›r wall area in furnace	2,528 sq. ft.
rature to stoker windbox	408° F.
ween side walls at stoker level . . .	34 ft. 11½ in.
(P.G.A.)	787 sq. ft.

(Taylor, Stoker and Babcock and Wilcox.)

Stoker.

Another feature of the water-tube boiler is its ability to withstand the high working pressures now used, *e.g.*, 600 to 2,000 lb. per square inch. This is rendered possible by the use of steam and water drums of small diameter. There are a number of special types of very high-pressure boilers in use for power stations, and these will be referred to separately.

The high-head boiler developed as a result of the necessity for higher pressures and temperatures, higher steaming capacities and higher rates of heat release. The amount of fuel burned necessitated that the furnace should be large ; the time factor to give complete combustion, particularly with pulverised fuel firing, required a tall furnace ; and the high steam temperatures required considerable superheater surface located in a suitable temperature zone.

Classification of Boilers. Boilers may be grouped into four classes :—

(1) Stoker Fired.
  (*a*) Chain grate (overfeed travelling).
  (*b*) Multiple retort (underfeed pusher).
(2) Pulverised Fuel Fired.
  (*c*) Unit (direct system).
  (*d*) Central (bin and feeder system).
  (*e*) Combination of (*c*) and (*d*).
(3) Oil Fired.
(4) Peat Fired.

Stoker Fired Versus Pulverised Fuel Fired. One of the chief factors in the economical working of a power station plant is efficient combustion of the fuel. Whether this can be obtained more efficiently by stoker or pulverised fuel firing depends largely on a number of features, some of which are :—

(1) Characteristics of the coal available.
(2) Capacity of boiler unit.
(3) Station load factor.
(4) Load fluctuations.
(5) Reliability and efficiency of the various types of combustion equipment available.

Both stoker and pulverised fuel equipments have been used on small and very large boiler units and have proved satisfactory. In some cases a combination of both has been adopted to obtain the benefits of cheaper coals and also meet the sudden demands for steam. In one base load station half stoker and half pulverised fuel plant was installed, the latter being chosen with a view of utilising the dust available from the dry coal cleaning plants in the district. This appears to be a sound choice and a possible alternative

would be the use of retort stokers where a station is away from the coalfields and a continuous supply of selected coal is available.

Probably the easiest way to compare stoker and pulverised fuel firing is to summarise the advantages and disadvantages of each method.

Stoker Fired

Advantages.

(1) The coal is burned as delivered to site, thus obviating the need for coal preparation plant. Where coal is supplied as lump or "run of mine" free from duff and small coal, preparation plant would be required.

(2) Generally less building space is necessary.

(3) Reduction in auxiliary plant.

(4) Can be used for small or large boiler units.

(5) Very reliable, and maintenance charges are reasonably low.

(6) With the retort type some reserve is gained by the large amount of coal stored on the grate in case of coal-handling plant failure. The efficiency of this type is high if suitable coals can be obtained.

(7) Practically immune from explosions.

(8) Gives a general appearance and atmosphere usually associated with boiler houses which seems to have a psychological effect on the operatives. This is not an important feature, but is worth noting.

Disadvantages.

(1) With very large units the initial cost may be rather higher than with pulverised fuel.

(2) In the majority of chain-grate boilers special ignition arches are included which are liable to give trouble.

(3) There is a multiplicity of moving parts always under mechanical stress and high temperature. Complicated form of construction.

(4) The structural arrangements are not so simple, and surrounding floors have to be designed for heavy loadings.

(5) Troubles due to slagging and clinkering of combustion chamber walls are experienced.

(6) Always a certain amount of loss of coal in the form of riddlings through the grates.

(7) Sudden variations in the steam demand cannot be met to the same degree.

(8) Banking and standby losses are always present.

Pulverised Fuel Fired

Advantages.

(1) It is possible to consume efficiently almost any grade of coal with small or large boilers.

(2) This method is flexible and sudden variations in the steam demand can be met with equal swiftness.

(3) A boiler unit can be started up from cold rapidly and efficiently. This is highly important in times of emergency.

(4) Standby losses are reduced to a minimum and banking losses are eliminated.

(5) A higher efficiency is made possible due to complete combustion, and further, this can be maintained over long working periods. The chimney discharge is almost colourless if flue gas cleaning plant is installed.

(6) Practically free from slagging and clinker troubles.

(7) The furnace has no moving parts subjected to high temperature.

(8) The structural arrangements and flooring are simple.

(9) Can be easily and efficiently operated, and labour charges are reduced on very large units.

(10) Preheated air temperatures of 700°F. are possible, thus promoting more rapid flame propagation.

(11) Gives immunity from bonded deposits on, and corrosion of, external heating surfaces.

Disadvantages.

(1) Coal preparation plant is necessary.

(2) Considerable increase in auxiliary plant.

(3) Maintenance on furnace brickwork is considerable, due to the very high working temperatures. Fin-tube walls are now used. Maintenance charges on the preparation plant is usually high, but depends chiefly on the quality of coal used and the resulting wear it produces.

(4) In some cases, particularly smaller boiler units, the first cost may be higher than with stoker firing.

(5) This type of plant is always prone to explosions, and provision must be made to deal with same.

(6) Special starting-up equipment is necessary.

(7) Larger building space would normally be required especially with the central system.

(8) Owing to the large quantities of very fine grit and dust produced, larger and more elaborate gas cleaning plant is required. Special dust catchers or precipitators are essential. In residential districts a serious nuisance may be caused by the emission of these very fine particles of grit and dust.

Comparison of Various Classes. Having dealt with the respective merits and demerits of stoker and pulverised fuel fired plants, the various classes will be outlined. The chain grate and retort stokers will be first considered.

(*a*) Chain Grate

Advantages.

(1) Very simple, reliable, accessible and maintenance charges are reasonably low.

(2) Lower first cost.

(3) Usually much lighter in weight.

(4) Generally a higher heat release per cubic foot of combustion chamber is possible. There are cases where the reverse holds good.

(5) It is practically self-cleaning.

(6) Almost any class of coal can be efficiently burned, but the range for a given stoker is limited.

(7) Not so heavy looking and gives a better appearance at operating floor level.

(8) Ash crushers are not normally required.

Disadvantages.

(1) Small amount of coal is carried on grate.

(2) Specially designed ignition arches are generally required.

(3) Slagging and clinker troubles are met with.

(4) With very fine coal the quantity of riddlings may be considerable.

(5) The preheated air temperature is limited to about 350° F. maximum. Usual working temperature is between 250° to 300° F.

(6) Where the fire is thinned down at the rear of the grate there is the possibility of ingress of excess air.

(*b*) Retort Stoker

Advantages.

(1) Higher efficiency is generally possible compared with chain-grate stoker.

(2) Much higher steaming rates are obtainable and is a good substitute for pulverised fuel. Care is however required and easy ratings are preferable.

(3) Ignition arches if required are simpler and maintenance charges are reduced.

(4) A large amount of coal is carried on the grate, thus ensuring high overload capacity and permitting the boiler to remain in service for a considerable period in the event of coal supply failure.

(5) Very robust construction and can withstand long periods of uninterrupted high capacity working without injury providing coal selection, maintenance and operation are of the first order.

(6) The cast-iron tuyeres, grate-bars, etc., are in contact with green coal, only and are kept cool by air passing through them.

(7) The grate is practically self-cleaning but slagging and clinker troubles are still possible.

(8) Higher preheated air temperatures are possible.

(9) Use can be made of an ash crusher pit to get the maximum amount of heat from the coal.

Disadvantages.

(1) Higher first cost.

(2) If load is suddenly dropped for prolonged periods, boiler may continue to blow off due to the large amount of coal on grate.

(3) Failure to ignite with very low grades of coal.

(4) Difficulties are sometimes experienced due to large solidified masses of ash produced which give rise to trouble in the ash-handling system and also result in destruction of the grate by burning out. Ram pins shear due to jamming and the boiler has to be shut down and cooled off to clear away clinker.

(5) Larger building space is usually necessary and the stoker is heavier.

The next to be considered will be the unit and central systems of pulverised fuel firing.

(*c*) Unit System

Advantages.

(1) Cheaper than central system.

(2) Less equipment required and plant can be arranged to provide a roomier and lighter layout.

(3) The layout is simple and permits of easy operation.

(4) The power consumption per ton of coal is usually slightly less.

(5) Fewer plant operators are required and operation costs are therefore reduced.

(6) Lower maintenance charges.

Disadvantages.

(1) Duplication of coal preparation plant or at least some degree of reserve is necessary.

(2) Exhauster fans handle air and pulverised coal, the latter causing excessive wear.

(3) The coal preparation plant has to operate under fluctuating conditions in accordance with the variation of boiler load demand. The maximum load for this plant coincides with the station maximum load, and extra generating plant is therefore necessary.

(4) The degree of flexibility is less than the central system, although it is somewhat improved by using two or three units per boiler.

(5) Adjustments to burners usually necessitates alterations to the working of coal preparation plant. Interdependency of pulverising and firing process is not conducive to maximum combustion efficiency.

(6) Large amount of wear takes place in coal preparation plant which reduces output and fineness. After long working periods this will result in a considerable reduction of boiler output and efficiency.

(7) The fuel flow to the burners is not so uniform or dependable as in the central system. The flow depends primarily on the raw coal size and moisture content.

(8) Blockage of feeders caused by tramp iron, wood, rag, etc., may temporarily stop the coal supply and put the boiler out of commission.

(9) Coal drying by blod flue gas is possible, but burner efficiency is impaired due to reduction in oxygen per unit of volume of combustion air.

(10) Owing to the limited fuel capacity there is a need for stricter maintenance.

(*d*) Central System

Advantages.

(1) Boiler plant is more reliable since failure of coal preparation plant does not immediately affect operation.

(2) Large degree of flexibility, as fuel and air quantities can be accurately controlled enabling the boiler outputs to be varied over a wide range.

(3) By providing storage bunkers the coal preparation plant can be shut down during peak loads thereby reducing the works auxiliary load at these periods.

(4) The coal preparation plant can be worked continuously at its designed rating, and therefore maximum efficiency; further, the correct fineness of fuel will be readily obtainable. The fuel is made on a mass production basis with consequent savings.

(5) Exhauster fans only handle air, consequently very little wear takes place.

(6) The burners can be operated irrespective of the coal preparation plant.

(7) It lends itself to fuel drying in the coal preparation plant by means of bled flue gas, the latter being returned to the boiler at a suitable point.

(8) The amount of spare plant can be reduced.

Disadvantages.

(1) Greater capital cost.

(2) Larger building space required. Possibly a separate coal preparation plant building.

(3) More plant operators are required, thus increasing operation charges.

(4) Maintenance charges are higher.

(5) Susceptible to fire and explosion hazards.

(6) The auxiliary power consumption is much higher.

(7) Greater number of auxiliary units, *i.e.*, cyclones, conveyors, storage bins, primary air fans, etc.

It may be added that with large boiler units now contemplated it appears economically justifiable to adopt the bin-and-feeder system for each boiler, which is really a unit form of storage system.

Oil Fired

Oil firing can be used for boilers of outputs generally associated with coal-firing, and the new Bankside Power Station is the largest in this country. Oil fuel effects economies in handling; increases the plant availability and efficiency; there is no disposal of refuse; no banking or lighting-up losses; ash-pit losses are eliminated; repairs and maintenance of stokers and pulverisers associated with such plants are much greater than those for oil-burning plants. Flue-gas washing, if necessary, would still be desirable with oil-firing plant, but grit arresters and precipitators need not be used.

Superheaters are prone to a hard and adhesive oil slag which is often difficult to remove, but other heating surfaces are almost trouble-free. In changing a boiler from coal to oil-firing the superheat will be lowered due to the increased heat absorption of the cleaner furnace heating surfaces. A typical fuel analysis is :—

	Per cent.
Carbon	84·0
Hydrogen	12·0
Sulphur	2·0
Oxygen	1·0
Nitrogen	0·5
Moisture	0·5
	100·0

Gross calorific value	18,300 B.Th.U. per lb.
Specific gravity	0·98
Flash point (closed test)	200° F.

Efficient combustion is obtained with about 12 per cent. excess air at boiler outlet corresponding to a CO_2 content of 14 per cent.

Typical Heat Balance Sheets

	Oil Per cent.	Coal Per cent.
Heat in dry gases at exit	3·8	6·3
Heat in moisture at exit	6·9	3·8
Total heat in gases at exit	10·7	10·1
Heat entering with combustion air	1·3	1·6
Chimney loss	9·4	8·5
Ashpit loss	—	0·9
Loss by radiation	2·6	2·6
Heat transferred	88·0	88·0
	100·0	100·0

The approximate relative costs of oil and coal-firing plants are given in Table 19.

The Bankside power station is being built in two halves, each consisting of two 60 MW sets with four 375 k.p.h. boilers. Three of the boilers operating at about 90 per cent. output are capable of steaming the two sets at full output. Each boiler is a single-drum natural-circulation water-tube boiler with water-cooled combustion chamber, primary and secondary horizontal drainable convection type superheaters, plain steel tube economiser and primary and secondary air heaters. The secondary air heater is of the plain steel tubular type and the primary heater, which handles the cooler flue gases, is a gilled cast-iron type. There is a boiler convection bank between the primary superheater and the economiser. The tubes forming the superheater and convection heating surfaces have wide pitching so that slag accumulations will fall clear when removed

TABLE 19

Item		Oil Firing	Coal Firing (Stoker)	
			Base Load Station	Secondary Station
Boiler capacity . .	1,000 lb./hr.	100–350	350	100
Gross efficiency . . .	per cent.	88	88	81
Banking and lighting up .	,, ,,	—	0·6	3
Nett efficiency . . .	,, ,,	88	87·4	78
Calorific value . .	B.Th.U./lb.	18,300	11,500	11,000
Price per ton	s.	82	52	46
R. and M. handling cost per ton .	s.	1	2·5	4·5
Overall fuel, cost per ton . .	s.	83	54·5	50·6
Overall cost per 1,000 lb. steam .	d.	32	33	37
Availability . . .	per cent.	85	75	75
Capital charges per 1,000 lb. steam	d.	11	12	14
Total cost per 1,000 lb. steam .	d.	43	45	51
Saving per 1,000 lb. by conversion to oil	d.	—	2	8
Annual saving per boiler . .	£	—	12,000	16,000

Also see Chapter XVI, Vol. 2.

from the tubes. Provision is made for water-washing of the primary and secondary superheaters, boiler convection surface, economiser and primary air heater, which are arranged in separate compartments with a number of hoppers for the collection and removal of the effluent. A small-capacity extraction plant deals with the flue dust. Twelve oil burners of the pressure atomising type are arranged in two rows in the front wall of the combustion chamber. Each burner is fitted with gas pilot burners for ignition purposes. The burners are supplied with oil from pumping and heating units placed below the boilers. The oil pumps are driven by variable speed d.c. motors and deliver oil at a pressure of between 250–300 p.s.i. The oil temperature is raised to about 250° F. for burning and the boiler output is controlled by varying the number of burners in use and also by varying the oil pressure. Electrically-operated steam soot blowers are automatically operated in sequence from a panel at firing floor level.

Two two-speed vane control forced draught and two two-speed induced draught fans are provided on each boiler. For test purposes an oil fuel weigh tank is provided to ensure accurate measurement of the oil consumed.

The fuel used is a residual grade of heavy oil with properties similar to Bunker "C" grade oil. The oil has a gross calorific

value of about 18,250 B.Th.U. per lb., a specific gravity of 0·98 at 60° F. at a maximum viscosity at 100° F. of 6,500 seconds Redwood No. 1. The normal sulphur content is between 3 and 4 per cent. The oil is stored in three mild steel circular tanks each measuring some 92 ft. dia. × 24 ft. high with a capacity of 4,000 tons. Three further tanks may be required for the completed station of 240 MW. Three motor-driven circulating pumps, each of 44 tons per hour capacity at 40 p.s.i. are situated in the storage area and pump oil through a ring main to the boiler house and back to the tank. At normal tank levels a gravity feed to the boiler house is used. Because of the high viscosity the oil is maintained at a temperature of not less than 110° F. for ease of handling. Steam heating coils are included at the base of each storage tank and all pipe lines are traced with one or two 1-in. steam lines. The jetty off loading and boiler house circulating pumps, filters, etc., are steam jacketed. To supply the steam for oil heating, a separate auxiliary system working at 250 p.s.i. saturated is provided. Steam at this pressure is required for the oil heaters associated with the boilers, and for tank and oil pipe heating the steam is reduced to 50 p.s.i. The steam is supplied either by two high-pressure evaporators through steam coils connected to the 900 p.s.i. steam range, each having an output capacity of 18,000 lb. per hour, or by two economic type horizontal oil-fired boilers, each with a capacity of 5,000 lb. per hr. All drains are conserved and returned to the evaporators or economic boilers *via* a de-oiling and filtering plant. The oil consumption for the completed station will be 67 tons per hr. at full load or 850 tons per day for full two-shift working (16 hrs. per day).

The principal details of the boilers are as follows :—

	N.E.R.	M.C.R.
Evaporation, lb./hr.	300,000	375,000
Steam pressure, p.s.i.	950	950
Steam temp., °F.	925	925
Feed temp. at economiser inlet, °F.	370	370
Feed temp at economiser outlet, °F.	475	500
Air temp. at heater inlet, °F.	100	100
Air temp. at heater outlet, °F.	520	540
Final gas temp., °F.	331	350
CO_2 at furnace exits, per cent.	13·7	13·7
CO_2 at induced draught fan, per cent.	12·0	12·0
Total draught loss, in W.G.	5·72	8·89
Furnace heat release, B.Th.U./ft.^{3}	17,900	22,500
Gross thermal efficiency, per cent.	86·5	85·9
Oil consumption, lb./hr. (18,250 B.Th.U.)	21,300	26,800
Furnace volume, ft.^{3}	21,750	

Furnace dimensions (between centres of tubes): Width 22 ft. 4 in., depth 18 ft., height 56 ft.

Heating surface :—

	sq. ft.
Water walls	13,025
Convection bank	4,230
Risers from convection bank	2,460
Primary superheater	7,543
Superheater connecting tubes	1,625
Secondary superheater	6,260
Economiser	11,540
Primary air heater	22,048
Secondary air heater	50,000

It is estimated that some 40,000 tons of oil will be consumed annually. This will contain about 1,600 tons of sulphur, which during the process of combustion would form some 3,200 tons of oxides of which about 5 per cent. would be discharged into the atmosphere. The flue gas washing plant is described in a later section. Based on 1949 prices, the comparative costs of production with a station load factor of 40 per cent. are approximately as follows :—

Oil burning	0·69*d*. per unit generated.
Coal burning	0·76*d*. ,, ,, ,,

Peat Fired

One such station is in operation at Portarlington (Ireland) and comprises 2–12·5 MW, 10 kV., 3,000 r.p.m. sets and 3–150 k.p.h., 425 p.s.i., 825° F. boilers, one reinforced concrete cooling tower with make-up water taken from a river. The station is situated some four miles from the peat bog, which has an area of some 4,000 acres. The bog is equipped with turf-winning machinery capable of producing 120,000 tons of fuel per annum, which is estimated to produce 90,000,000 kWh. per annum.

Behind the boiler-house and spanned by a bridge crane is the fuel store, capable of holding 40,000 tons of turf (12,500 sq. ft.). The turf, which is machine-won and air-dried, is delivered direct from the bog to the station in steel trucks, each holding 5 tons. On arrival the turf is weighed and samples are taken for analysis and determination of moisture content. It is then fed direct to the boiler-house bunkers or alternatively to the fuel store. The bridge crane (8 tons) lifts each truck off its bogie and transfers it to the storage area, tilts the truck to allow a hinged door at the end to open and so discharge the turf. When the fuel is delivered direct to

the boiler-house bunkers the turf trucks are unloaded in a similar manner by two jib cranes mounted on a runway fixed to the boiler-house roof. Some sixty loads of turf are required to fuel each bunker, which has a capacity of 300 tons. Each of the steel bunkers converges at the bottom to a vertical drying shaft, which guides the turf down to the boiler. As the turf descends by way of the shaft, hot air is blown through it to reduce the moisture content. The turf then passes on to a chain grate stoker. The ash falls from the grate at the rear of the boiler into hoppers and in the form of clinkers it is then crushed and removed mechanically to a disposal plant, which cools the ashes and discharges them into wagons for disposal.

The turf consumption is about 3 lb. per kWh. generated, which at 39*s*. 6*d*. per ton gives a fuel cost of 0·635*d*. per kWh. The moisture content of the air-dried turf is about 30 per cent. and calorific value 6,200 B.Th.U. per lb. The estimated total capital cost of the completed station is £1,280,000 or £51·2 per kW. installed. Interest, depreciation, maintenance and repairs, etc., are approximately 0·393*d*. per kWh., making the total cost of production about 1·028*d*. per kWh. Two further peat-burning stations each having an installed plant capacity of 40 MW are under consideration.

BOILER

The boiler proper consists of a combustion chamber together with all tubes, headers and allied steam and water drums. The arrangement of these items will depend largely on the make of boiler.

The ancillary plant such as superheaters, air heaters, economisers, stokers and draught plant, etc., although they make up a complete boiler unit, will be dealt with individually.

A typical specification clause would read as follows :—

" The boiler shall be of the water-tube type, capable of evaporating 200,000 lb. of water per hour under normal working conditions and 250,000 lb. of water at maximum continuous rating at a pressure of 625 lb. per square inch gauge and at a temperature of 850° F. when supplied with feed water at a temperature of 315° F. to 320° F. and coal having a gross calorific value of 11,500 B.Th.U.'s per lb. as fired containing 10 per cent. moisture and 10 per cent. ash with air entering the air preheater at a temperature of 90° F."

The design of any boiler plant depends primarily on the following :—

(1) The steam pressure and temperature.
(2) Evaporative capacity.

(3) Classes of fuel.
(4) Method of firing—stoker, pulverised fuel, oil, or peat.
(5) Thermal efficiency desired.

Because of difference in specific volume, more tube area is required for low-pressure steam than for high, if proper circulation is to be maintained. Difference in area required may be of the order of 3 or 4 to 1 between 200 and 1,500 p.s.i. This explains why high-pressure boilers cannot always be operated satisfactorily at low pressure and why a boiler bought for future operation at higher pressure costs more than one built for the high-pressure originally. The lowering of pressure very suddenly by the failure of some part of a boiler may result in much of the water being flashed into steam, causing a serious explosion. One pound of steam at atmospheric pressure occupies about 1,600 times the space occupied by 1 lb. of water, and the explosive energy released by a rapid pressure drop is very great.

Combustion Chamber. The combustion chamber or furnace is the chamber in which combustion is effected. Its design, proportions and details are of utmost importance to the success of the boiler unit. The heat resulting from combustion reaches the tubes by radiation and convection, the former being a process of heat transmission through space, and the latter a process of heat transference by means of currents of gases which impart their heat by contact with the tubes. The water in the tubes is heated by conduction through the tubes. These processes are assisted by any increase in the combustion chamber temperature, but the greatest benefit is obtained from the heat transmitted by radiation. The rate at which heat is radiated is given by Stefan's Law as being proportional to the fourth power of the absolute temperature. For example, the heat radiated may be increased four-fold by an increase of from 2,000° F. to 3,000° F. in temperature.

The amount of heat imparted to the heating surfaces by convection currents may be considered to be approximately proportional to the temperature difference between the hot gases and metal surfaces, though the cleanliness of the surfaces is of utmost importance. Bird-nesting of tubes impairs heat transfer and draught and when this occurs the grates, ash plates, bearer bars and dumping bars become very hot.

Whilst high gas velocities assist in preventing deposition of soot they are not conducive to radiant heat absorption and the velocities chosen should meet all requirements. The volume of the combustion chamber should be such that the maximum rate of heat

liberation is limited to a figure that will ensure trouble-free operation and low maintenance costs and reduce outages. In practice the figures vary over wide limits, as will be observed from Table 20, which include the heat in the preheated air. From a survey of some high availability boilers it is noted that the maximum heat release was of the order of 17,500 B.Th.U's per cu. ft. per hour.

TABLE 20. *Heat Release Data*

	150,000 lb. per Hour.	—	187,500 lb. per Hour.		110,000 lb per Hour.	— 130,000 lb. per Hour
Maximum Heat liberated per cubic ft. of Combustion Chamber Volume in B.Th.U. per Hour.						
Maker	Chain Grate Stoker		Retort Stoker		Pulverised Fuel	
	N.E.R.	M.C.R.	N.E.R.	M.C.R.	N.E.R.	M.C.R.
A.	36,600	46,000	22,500	28,300	17,000	20,000
B.	32,000	40,000	28,300	35,600	15,500	18,750
C.	19,300	24,300	19,900	27,800	15,000	18,000

For good radiant heat absorption and reduction of fly ash it is contended that the horizontal sectional area should be large and the speed of the gases low.

The length of the gas travel should be sufficient to ensure complete combustion before arrival at the banks of comparatively cool boiler tubes. One of the most important developments in the quest for larger output was the replacement of the refractory brick setting by a water-cooled furnace, to enable a greater quantity of fuel to be burned per cu. ft. of furnace volume. Combustion chamber walls are lined with vertical tubes through which the water circulates, the tubes being expanded into steel headers at the bottom and headers or steam drums at the top. The spacing and arrangement of tubes should provide the correct proportions in relation to combustion chamber volume, wall surface area, protection of refractories, prevention of smoke, etc.

The roof of the combustion chamber is formed by refractory blocks supported on and cooled by tubes expanded into drums and headers. The tendency in both stoker and pulverised fuel fired boilers is to encage the whole of the combustion chamber by water tubes. The purpose of these tubes is to provide additional heating surface for the boiler and to afford protection of refractories by cooling. The entire elimination of refractories tends towards obtaining high availability. Some combustion chambers are,

with the exception of the front walls and ash chambers, without refractory material. This has been achieved by using finned tubes. These tubes are standard boiler tubes 3¼ in. o/dia. set in headers on a

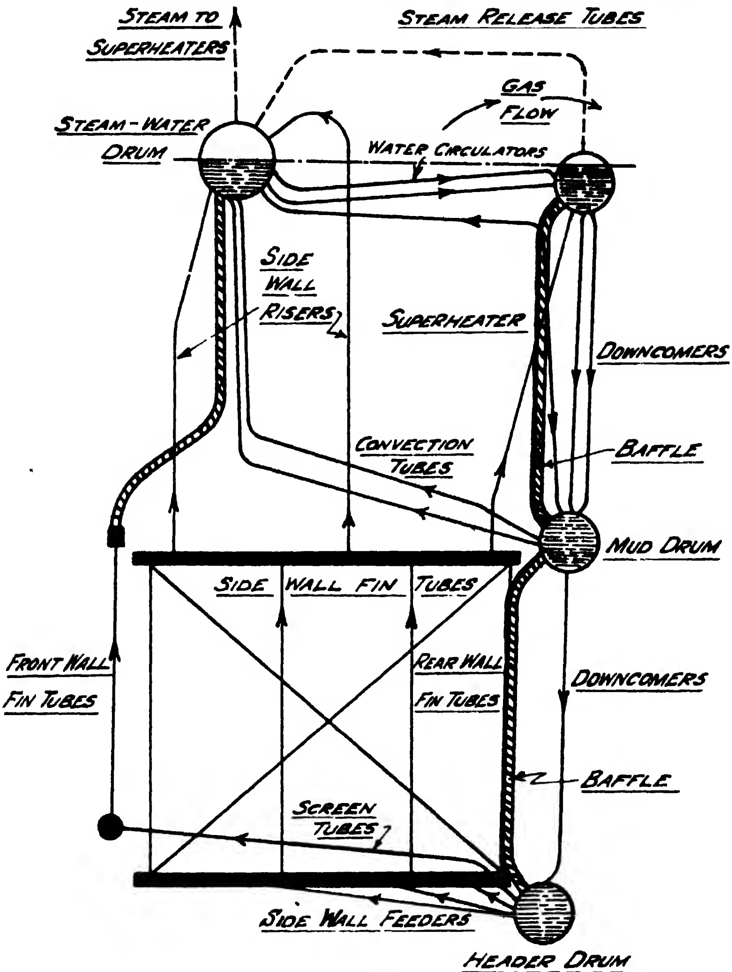


FIG. 122. Diagrammatic Arrangement of Circulation for "Lopulco" Boiler. (*International Combustion Ltd.*)

pitch of 5⅜ in. and coupled into the main boiler circulating system. Each tube has mild steel fins ¼ in. thick and 1 in. wide welded on each side and when the tubes are placed in position the fins almost butt to form a complete steel wall. To reduce radiation losses these tubes are backed by 2 in. of heat-insulating material in the casing. The front wall accommodates the burners and so makes difficult the use of the

fin tube. To prevent high temperatures damaging the brickwork, plain tubes are used as a partial screen and set to avoid the burners.

Figs. 122 and 122A illustrate typical circulation systems for two well-known types of boilers.

Ash which exists in molten form in the hottest part of the furnace should solidify before coming in contact with the walls and it is therefore necessary that the walls should be brought well below fusion point. If this precaution is not taken "fluxing" or "slagging" may take place, the former causing rapid erosion of the walls and the latter "spalling" of the refractory due to the difference between the rates of contraction of the slag and the refractory. The various types now in use illustrate the functions of water-cooled walls. In some types the tubes are protected by blocks of either metallic or silicious material, some are partly buried in refractory lining, some are finned so that they gain the full radiant heat, whilst others are fully exposed in front of a solid wall. The "Bailey" water wall has been extensively used for tube protection, there being two general forms of blocks. The first is formed by casting the iron body of the block on to a refractory tile, it is then machined so that it can be tightly clamped to the tube and so give maximum heat transfer. This is for use in the upper or high temperature portion of the combustion chamber. The second is for use where the temperature is not excessive, such as the lower part of the combustion chamber, and is made of solid cast-iron. Some of these walls have been in service for many years and although a number of the blocks have worn very thin a number of them in the lower temperature zones could be

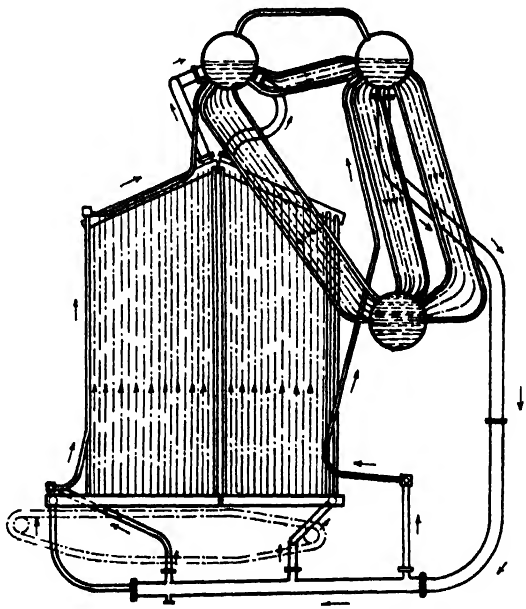
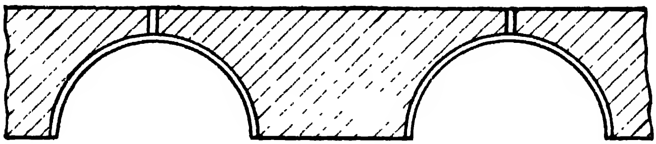
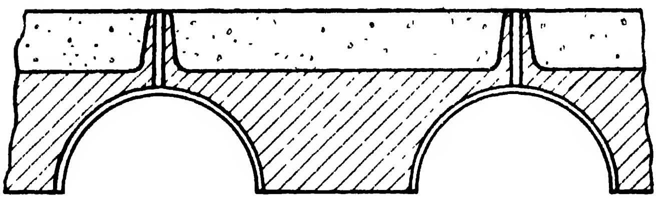


FIG. 122A. Diagrammatic Arrangement of Simon-Carves Patent Circulating System.

used again. Typical sections are illustrated in Fig. 123. Cases are on record where explosions have taken place in combustion chambers due to the deterioration under working conditions of the refractory brickwork. In such instances this has resulted in the exposure of several of the embedded cooling tubes to the direct heat of the furnace. Under these severe working conditions (not designed for such working) the circulation within the tubes was inadequate and overheating occurred resulting in a tube being unable to withstand normal working pressure. The water wall tubes are intended to absorb the radiant heat which would otherwise heat up the furnace



FOR USE IN LOWER PORTIONS (LOW TEMP) OF COMBUSTION CHAMBER



FOR USE IN HIGHER PORTIONS (HIGH TEMP) OF COMBUSTION CHAMBER

FIG. 123. Typical Water Wall Blocks.

walls. The feedwater in this case was first made to circulate through the water wall tubes before gaining access to the main generating tubes. Without a covering of refractory material steam was apparently generated in these tubes and there being insufficient circulation of water or steam resulted in overheating and consequent failure.

Air cooling of walls has been used on sections of the chamber around the burners of pulverised fuel units. A number of small tubes are taken through the walls from the air ducts and are effective in protecting the refractories in the vicinity of the burners.

Cyclone Furnace. The coal is crushed, the aim being to reduce

the whole of the ash to a fluid state, so that it may be tapped and subsequently quenched to a solid state for disposal. The primary furnace takes the form of a water-cooled cylinder set in front of the main combustion chamber. The crushed coal is introduced at the centre of the "outboard" end of the cyclone with a tangential swirling movement. The entire inner surface of the cyclone in operation is covered with a film of molten slag which traps most of the particles which would otherwise escape as fly-ash. It is claimed that it obviates the cleaning of external boiler surfaces, protects induced draught fans from erosion, and reduces fly-ash and carbon losses. Raw coal is crushed to pass a 4-mesh screen (about 0·2 in.), the rate of flow being automatically controlled. Crushing is aided by preheated primary air and the small proportion of finer particles enable ignition to be obtained and maintained. Operation has been almost trouble-free, for only intermittent lancing of the cyclone, together with soot blowing of the closely pitched superheater tubes, have been required. External combustion offers the chance to avoid the use of soot-blowing and deslagging equipment. A cyclone furnace for a 540,000 lb. per hour boiler operates at about 3,200° F. and 83 per cent. of the ash from 2 in. crushed coal is liquefied and then quenched for disposal in a solid state. After allowing for 7 per cent. shrinkage in the iron compounds, only 10 per cent. of the ash (below 10 microns) traverses the furnace and convective passes, compared with 75 to 85 per cent. for pulverised fuel in a dry-bottom furnace and 55 to 65 per cent. in a slag-top furnace.

Slag-Tap Furnace. Pulverised fuel, although almost essential for very large boiler plants and possessing much great flexibility to meet automatic control requirements, has an important drawback in the amount of fly-ash which is produced by fuels burning in suspension and which requires costly collection and precipitation plant. A development which considerably reduces fly-ash is the slag-tap furnace, in which the combustion chamber is divided into two sections. The primary furnace, where combustion takes place from down-shot burners, is purposely designed to operate at a temperature well above that of ash fusion ; so that the furnace bottom is covered with a film of molten slag, which is continually tapped away to be water-quenched. This film entraps a large proportion of the particles which would otherwise be carried off as fly-ash. There is only one station (Stourport) in this country using this type of furnace but there are a number in America. The coal characteristics are a determining factor in its adoption.

Steam and Water Drums. To provide free-water circulation a steam space of adequate volume should be included to prevent water being delivered with the steam. A noticeable feature is the inclusion of a dry-steam drum or steam receiver drum which removes any possibility of trouble from the creation of foam due to the mixtures of steam and water in the lower drums. Impurities in the water become more and more concentrated as evaporation proceeds and eventually the water may become so dense that the steam bubbles cannot rise freely through it, resulting in masses of water being lifted with the steam towards the outlet. Further, it is desirable to have a steam-freeing surface large enough to enable the steam to separate from the water without undue disturbance. To guide circulation the drums are fitted with troughs and baffles and provision is made to ensure that only clean dry steam passes on to the superheater. The details vary according to the design and construction of the boiler. The water should be introduced where it does not discharge directly against any riveted joint or surface exposed to high temperature gas or direct radiation from fire. The internal fittings include feed distribution pipes, troughs, internal deflector plates to guide circulation, and screen plates for steam outlets and inlets together with anti-priming and steam purifying separators in the outlets of the main steam drums. The steam and water drums are supported on rollers or slung from girders which form part of the boiler structure. Allowance must be made for expansion and contraction to minimise the stresses put on the boiler structure.

With the use of high pressures, drum design, construction and selection of materials are of prime importance.

With designed pressures up to 350 p.s.i., riveted steel plate and fusion welded construction is quite satisfactory, but with pressures of 600 p.s.i. and over solid forged steel construction is employed. In practice it is found that the maker's routine varies as regards heat treatment and each drum is forged from a single ingot of Siemens-Martin open hearth acid mild steel, the ingot being thoroughly annealed after casting to remove all internal stresses. Each ingot is trepanned with a hole of adequate diameter to enable thorough examination to be made. The drums, after forging into cylindrical form, are normalised and stress relieved and are further stress relieved on completion of the closing in of the ends. The forging is heated in a properly constructed annealing furnace which raises the temperature of the forging uniformly throughout its entirety to the required intensity necessary for normalising and

stress relieving. Cooling is carried out to eliminate as far as is practicable the retention of any residual stress in the completed forgings. The forgings are machined internally to the required dimensions and the ends of the drums are closed in by forming under a forging process. The exterior of the final cylinder portion is machined and the drums should be truly circular and entirely free from camber. A manhole is provided at both ends of each drum to give access for inspection and maintenance. These are fitted with pressed steel hinged covers secured by steel dogs and bolts and have a 16 × 12 in. clear opening. There are various methods of connecting the branches or nozzles to the drums, two of which are (1) by studs and (2) by making the connections a driving fit in the drum shell, hammering over and then welding For pressures up to 400 p.s.i. the branches may be riveted on. Such methods are discussed under " steam receivers " in Chapter VIII.

Typical figures of the physical properties and chemical analysis of the steel used for boiler drums working at 600 to 700 p.s.i. are given.

Ultimate tensile strength . .	32 to 36 tons per square inch
Yield point	16 to 18 ,, ,, ,,
Elongation	21 to 25 per cent. on 2 in.
Reduction of area	40 per cent.
Bending angle	180°

For small steam receiver drums an ultimate tensile strength of 28 to 32 tons per square inch is satisfactory. All at atmospheric temperature.

Carbon	0·33 to 0·37 per cent.	
Silicon	0·30 ,, ,,	(maximum)
Manganese	0·60 to 0·80 ,, ,,	
Phosphorus	0·05 ,, ,,	(maximum)
Sulphur	0·05 ,, ,,	(maximum)

An elevated temperature test is included and a typical clause would be as follows :—

" The elastic limit at a temperature of 550° to 560° F. shall not be less than 10·2 tons p.s.i., and for this purpose the elastic limit is to be defined as the stress which would give a permanent set not exceeding 0·05 per cent. of the original length measured on a standard test piece of 2 in. gauge length. The drums to have a safety factor of 1·9 based on the elastic limit as defined above under working conditions, the stresses in question being those arising out of steam pressures together with the loading due to the suspended and supported weight."

Steam and Water Drums. To provide free-water circulation a steam space of adequate volume should be included to prevent water being delivered with the steam. A noticeable feature is the inclusion of a dry-steam drum or steam receiver drum which removes any possibility of trouble from the creation of foam due to the mixtures of steam and water in the lower drums. Impurities in the water become more and more concentrated as evaporation proceeds and eventually the water may become so dense that the steam bubbles cannot rise freely through it, resulting in masses of water being lifted with the steam towards the outlet. Further, it is desirable to have a steam-freeing surface large enough to enable the steam to separate from the water without undue disturbance. To guide circulation the drums are fitted with troughs and baffles and provision is made to ensure that only clean dry steam passes on to the superheater. The details vary according to the design and construction of the boiler. The water should be introduced where it does not discharge directly against any riveted joint or surface exposed to high temperature gas or direct radiation from fire. The internal fittings include feed distribution pipes, troughs, internal deflector plates to guide circulation, and screen plates for steam outlets and inlets together with anti-priming and steam purifying separators in the outlets of the main steam drums. The steam and water drums are supported on rollers or slung from girders which form part of the boiler structure. Allowance must be made for expansion and contraction to minimise the stresses put on the boiler structure.

With the use of high pressures, drum design, construction and selection of materials are of prime importance.

With designed pressures up to 350 p.s.i., riveted steel plate and fusion welded construction is quite satisfactory, but with pressures of 600 p.s.i. and over solid forged steel construction is employed. In practice it is found that the maker's routine varies as regards heat treatment and each drum is forged from a single ingot of Siemens-Martin open hearth acid mild steel, the ingot being thoroughly annealed after casting to remove all internal stresses. Each ingot is trepanned with a hole of adequate diameter to enable thorough examination to be made. The drums, after forging into cylindrical form, are normalised and stress relieved and are further stress relieved on completion of the closing in of the ends. The forging is heated in a properly constructed annealing furnace which raises the temperature of the forging uniformly throughout its entirety to the required intensity necessary for normalising and

stress relieving. Cooling is carried out to eliminate as far as is practicable the retention of any residual stress in the completed forgings. The forgings are machined internally to the required dimensions and the ends of the drums are closed in by forming under a forging process. The exterior of the final cylinder portion is machined and the drums should be truly circular and entirely free from camber. A manhole is provided at both ends of each drum to give access for inspection and maintenance. These are fitted with pressed steel hinged covers secured by steel dogs and bolts and have a 16 × 12 in. clear opening. There are various methods of connecting the branches or nozzles to the drums, two of which are (1) by studs and (2) by making the connections a driving fit in the drum shell, hammering over and then welding For pressures up to 400 p.s.i. the branches may be riveted on. Such methods are discussed under " steam receivers " in Chapter VIII.

Typical figures of the physical properties and chemical analysis of the steel used for boiler drums working at 600 to 700 p.s.i. are given.

Ultimate tensile strength	32 to 36 tons per square inch
Yield point	16 to 18 ,, ,, ,,
Elongation	21 to 25 per cent. on 2 in.
Reduction of area	40 per cent.
Bending angle	180°

For small steam receiver drums an ultimate tensile strength of 28 to 32 tons per square inch is satisfactory. All at atmospheric temperature.

Carbon	0·33 to 0·37 per cent.	
Silicon	0·30 ,, ,,	(maximum)
Manganese	0·60 to 0·80 ,, ,,	
Phosphorus	0·05 ,, ,,	(maximum)
Sulphur	0·05 ,, ,,	(maximum)

An elevated temperature test is included and a typical clause would be as follows :—

" The elastic limit at a temperature of 550° to 560° F. shall not be less than 10·2 tons p.s.i., and for this purpose the elastic limit is to be defined as the stress which would give a permanent set not exceeding 0·05 per cent. of the original length measured on a standard test piece of 2 in. gauge length. The drums to have a safety factor of 1·9 based on the elastic limit as defined above under working conditions, the stresses in question being those arising out of steam pressures together with the loading due to the suspended and supported weight."

The elevated temperature test is carried out at a temperature of 550° F. for the purpose of ascertaining the stress which will give a permanent set of 0·05 per cent.

The test piece is placed in the testing machine and heated slowly by an electric furnace to a temperature of 550° F. and maintained at that temperature for a sufficient period to ensure that both the test piece and the extension measuring apparatus are at a uniform temperature before proceeding with the test. A load of 2 tons per square inch is slowly applied to take up any shock in the testing equipment and afterwards the load is applied in increments of 0·2 tons per square inch, five seconds being taken to apply each increment and a further twenty-five seconds allowed to elapse in each case before the extension is noted. There is thus a half-minute interval between each increment of load. The results so obtained may be plotted in the form of a graph and a line drawn parallel to the straight portion of the graph and the point at which this line cuts the curve should be taken as the 0·05 per cent. proof stress. A typical set of figures relating to atmospheric and elevated temperature tests for boilers operating at 625 p.s.i. is given in Table 21.

TABLE 21. *Test Data*

Drum.	Test A.		Test B.		Forging Cast No.
	Breaking Stress (Tons per sq. in.)	Elongation (Per cent. on 2 in.)	Elastic Proof Stress (Tons per sq. in)	Permanent Set.	
Steam receiver	30–31·2	32–34	11·25–12 3	Not exceeding 0·05 per cent.	1,066
Front . .	34·4–36	27·5–31	13 7 15·3	,,	1,815
Rear . .	31·2–32·6	31·5–33	14·4–16·8	,,	1,914
Mud . .	36–38	27·5–28	13·4–14·35	,,	1,939

Although the term mud drum is still in use for the lower drum(s) of multi-drum boilers it is not intended to be taken as a description of its one-time function.

Tests. A ring from each end of the forging was subjected to :—

" A." Tensile test at atmospheric temperature.

(*a*) Breaking stress.
(*b*) Elongation on 2 in.

" B." Tensile test at a temperature of 560° F.

(*a*) Elastic proof stress.
(*b*) Permanent set not to exceed 0·05 per cent. of the original length of the test piece.

Before leaving the makers' works and boring for tubes, the drums are tested to a hydraulic pressure of not less than twice the maximum safety valve load. For example, if the designed drum pressure is 340 lb. per square inch then the hydraulic test pressure would be 680 lb. per square inch.

After erection on site, with all mountings in place and before covering in, each boiler is tested to a hydraulic pressure of not less than one and a half times the maximum safety valve load plus 50 lb. per square inch. Whilst these tests are being carried out the pressures should be steadily applied and maintained long enough for proof and inspection.

Table 22 gives details of such drums.

TABLE 22. *Dimensions of Steam and Water Drums*

	Designed Drum Pressure 710 lb. per square inch				Designed Drum Pressure 340 lb. per square inch				
Item.	Front.	Rear.	Mud.	Steam Receiver.	Front.	Rear.	Mud.	Header Drum.	Steam Receiver.
Internal dia. in.	42	48	48	30	48	48	48	30	36
Thickness in.	3	$3\frac{5}{8}$	$3\frac{3}{8}$	$1\frac{3}{4}$	$1\frac{1}{32}$	$1\frac{5}{8}$	$1\frac{5}{16}$	$\frac{3}{4}$	$\frac{7}{8}$
Overall length ft.	35	35	31	16	27	27	24	21	12
Approx. weight tons	22	34	29	$4\frac{1}{2}$	$8\frac{1}{2}$	$12\frac{3}{4}$	9	$3\frac{1}{2}$	$2\frac{1}{2}$

On completion of erection and testing of all tubes and drums they may be treated internally with special compounds to prevent pitting and corrosion.

Tubes and Headers. The arrangements of the tubes and headers vary according to the design of boiler and the positions in which they are placed. The size of tube will be primarily dependent on the rapidity of steam raising desired and the cleaning and maintenance necessary. Small tubes permit of rapid steam raising, but larger tubes are required if cleaning and maintenance is to be minimised. Figs. 124 and 125 show simplified arrangements. As already mentioned because of difference in specific volume, more tube area is required for low-pressure steam than high-pressure, if correct circulation is to be maintained.

Boilers are sometimes referred to as "straight tube" and "bent tube" boilers, and both types are now so well established that there is little to choose between them in so far as efficiency and general utility are concerned. Straight tubes with easy access were almost an

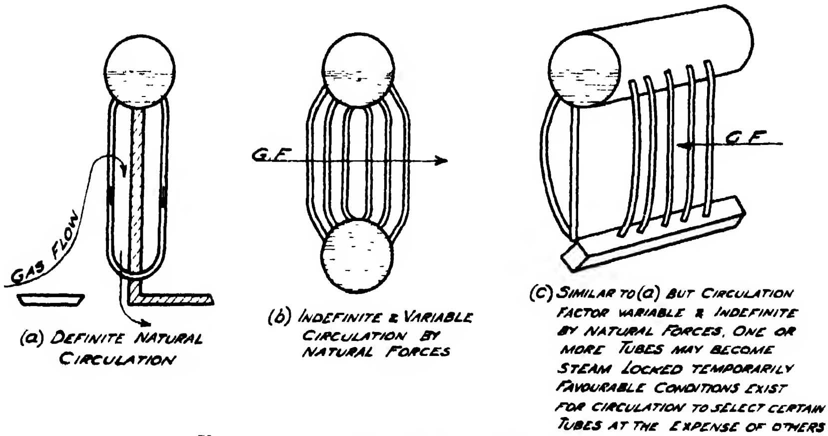


FIG. 124. Boiler Natural Circulating Systems.

essential in the early days of steam raising when raw water or water only slightly softened was used. With increasing temperatures and pressures the chemical treatment of water has become a matter of prime importance, so that easy access to tubes to remove choking scale is no longer a necessity, for scale should not be present. It is claimed that the more vertical inclination of the tubes is conducive to freer ebulition and easier steaming, and owing to the curvature of the tubes there are less strains on the boiler parts. Due to the curvature of the tubes and their smaller diameter, inspection may not be as easy as the straight types. There are fewer caps to be ground in and no special headers—apart from side walls—into which the tubes have to be expanded. Some engineers contend that external cleaning is not so frequent with "bent" tube boilers. In some designs tubes of 30 ft. in length have to be anchored to prevent distortion and each tube has two slotted lugs welded on the

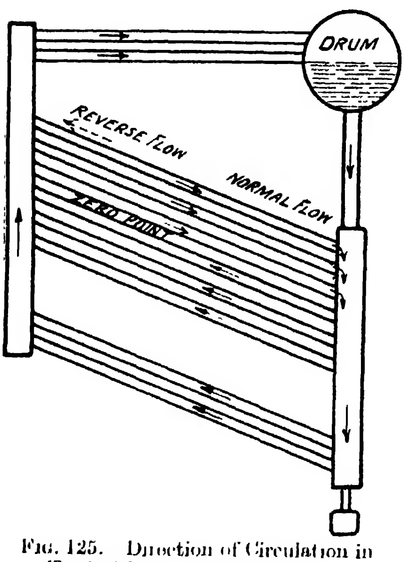


FIG. 125. Direction of Circulation in Typical Straight Tube Boiler.

back by which they are tied to the boiler structure. The slotting of the lugs is necessary to allow for expansion. The drums are rigidly supported and all expansion takes place in a downward direction. The water wall tubes are arranged in vertical sections formed by expanding the tubes at each end into headers. The tubes are expanded direct into the drums and headers so that their full cross-sectional area is available for passage of water and steam, thus providing sufficient thoroughfare for high speed circulation at minimum pressure difference. A hand-hole is placed near each tube in the headers so that the tube may be independently expanded, inspected or cleaned. Forged steel internal covers are fitted to each hand-hole and held in place by forged steel dogs and cap-bolts. These headers and wall tubes are supported by the steel frame and columns forming the combustion chamber structure, but are free to expand without danger of leakage, distortion or imposing stresses on the structure. The tubes are inclined from the horizontal in order that the water may flow in one direction under the influence of heat, the angles of inclination varying from 15° to 70°. It would appear that the vertical position would be better for allowing a free upward movement, but it is found that bubbles formed on the surface of a vertical tube do not free themselves easily, but tend to cling or crawl up the surface rather than to float off, and for this reason vertical tubes are not favoured as primary heating surfaces.

The steam and water cross-over tubes between drums should be such that a correct pressure difference is established and the water level maintained at all loads. Steam cross-overs ensure equal steam pressure in all drums, any tendency toward pressure differences between drums being counteracted by steam flow through the cross-overs.

All tubes should be arranged and spaced so as to reduce the accumulation of ash to a minimum and eliminate lanes in the gas path. The pitching of tubes varies with the design of boiler, but 6 in. and 6¾ in. are quite common, and for certain sections 9 in. spacing is adopted. Triangular spacing of the bottom rows of tubes has been used and found satisfactory.

The arrangement should permit of tubes being cleaned internally and externally throughout their entire length and allow of easy withdrawal and replacement of each tube without disturbing the remaining tubes. The ends of all tubes are annealed, trued and buffed before expanding. The annealing of tube ends for a 1,000 p.s.i. boiler was done by heating the ends to a dull red and then

plunging them into powdered lime, allowing them to cool off gradually.

As the efficiency of the attachment of the tube to the header or drum depends largely on the expanding and belling of the tube end, care should be taken to ensure that these operations are properly carried out (Figs. 126 and 127). The expanding tools should permit of easy manipulation and be such that the tubes are given a good "landing" in the tube hole. Careless expanding may result in unnecessary enlargement and consequent thinning of the tube. (Example of 4 in. 650 p.s.i. tubes, expanded to 4·087 in. and bell-mouthed to 4·218 in.) To prevent the tube being pulled out under working conditions, adequate belling of the tube end is essential, and to accomplish this the tube should project well into the header or drum. A figure of $\frac{3}{8}$ to $\frac{1}{2}$ in. is usual, except tubes in the highest row at the top of the drums and bottom headers which may be beaded to prevent air pocketing. All tubes should enter drums and headers normal to the surface.

Pitting and wasting of tube ends externally is usually the result of intermittent or prolonged leakage, however small, and is aggravated by the flue gases. Similar conditions are possible with superheater tubes. Tube failures have at times been caused by attack brought about by a combination of three conditions—high gas temperature, a reducing atmosphere and a salt content in the coal.

Tube materials are usually in accordance with the appropriate British Standard Specification and are of solid hot-drawn mild steel. In certain cases special alloy tubes may be necessitated by the temperature conditions obtaining.

Chemical analysis and sulphur prints are submitted for approval before proceeding with manufacture. The sulphur content should be as low as possible and evenly distributed throughout the metal.

Tube data relating to three types of boilers are given in Table 23.

The ratio $\frac{\text{water evap. per hr.}}{\text{water in boiler}}$ is the number of times the storage water is evaporated in one hour and is 1·9 approx. for the two examples given. The water storage capacity is very important when only a few minutes' total storage is available before a dangerous level is reached Some boilers have only 3 to 6 minutes' maximum supply and probably half this supply can only be used before it is necessary to reduce the loading.

Corrosion trouble is sometimes experienced with the tubes in boilers, especially the straight tube boiler. Fig. 128 illustrates the general arrangement of such tubes. In one boiler corrosion com-

FIG. 126. Rolled in Groove 3¼ in. o/dia. 3 S.W.G. Tube. Movement Nil at 21 tons (650 p.s.i. boiler).

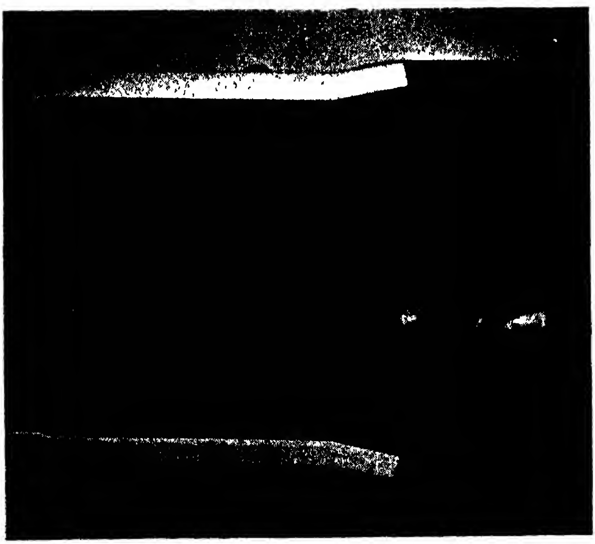


FIG. 127. Counterbored 3¼ in. o/dia. 4 S.W.G. Tube pulled out at 33 tons (650 p.s.i. boiler).

TABLE 23. *Tube Data*

Capacity	187,500 lb. per hour M.C.R. Designed Pressure 710 lb per sq. in.				187,500 lb. per hour M.C.R. Designed Pressure 710 lb. per sq. in.				130,000 lb. per hour M.C.R. Designed Pressure 340 lb. per sq. in.				
Type of Boiler	Chain Grate Stoker				Retort Stoker				Pulverised Fuel				
Section	Boiler	Front Wall	Side Wall	Rear Wall	Boiler	Front Wall	Side Wall	Rear Wall	Boiler	Front Wall	Side Wall (Fins)	Rear Wall (Fins)	Bottom Screen
Number of tubes	740	53	60	53	720	53	76	53	800	16	40	40	12
External diameter, in.	$3\frac{1}{4}$	—	—	—	—	—	—	—	$3\frac{1}{4}$ & 4	$3\frac{1}{4}$	—	—	—
Thickness, I.W.G.	4	2	3	3	4	2	3	3	7 & 6	7	—	—	—
Max. length, ft.	$29\frac{1}{2}$	36	13	19	$29\frac{1}{2}$	$33\frac{1}{2}$	$23\frac{1}{2}$	24	30	$29\frac{1}{2}$	30	24	14
Min. length, ft.	19	36	13	19	19	$33\frac{1}{2}$	$19\frac{1}{2}$	24	7	28	30	$20\frac{1}{2}$	14
Heating surface, sq. ft.	14,450	1,530	425	720	13,950	1,400	770	910	11,510	440	1,180	450	130

The projected grate area would be about 500 sq. ft. for the stokers, and this gives a ratio of heating surface to grate area of approximately 35·1. Weight of water in stoker boiler = 100,000 lb. Ratio $= \frac{\text{Water in boiler}}{\text{Water evap. per hr.}} = \frac{100,000}{187,500} = 0{\cdot}54$. Weight of water in pulverised fuel boiler = 70,000 lb. Ratio $= \frac{70,000}{130,000} = 0{\cdot}54$.

Bottom screen tubes are usually of heavier gauge.

menced about 7½ in. from the header and affected a total length of some 2 ft. of the tube. The actual wasting on the internal diameter of the tube commenced at a point at each bottom quarter and increased to its maximum depth at the top centre of the tube where the remaining thickness at the part which failed was reduced to $\frac{1}{16}$ in. bare. The failure of short lengths of tubes has led to the use

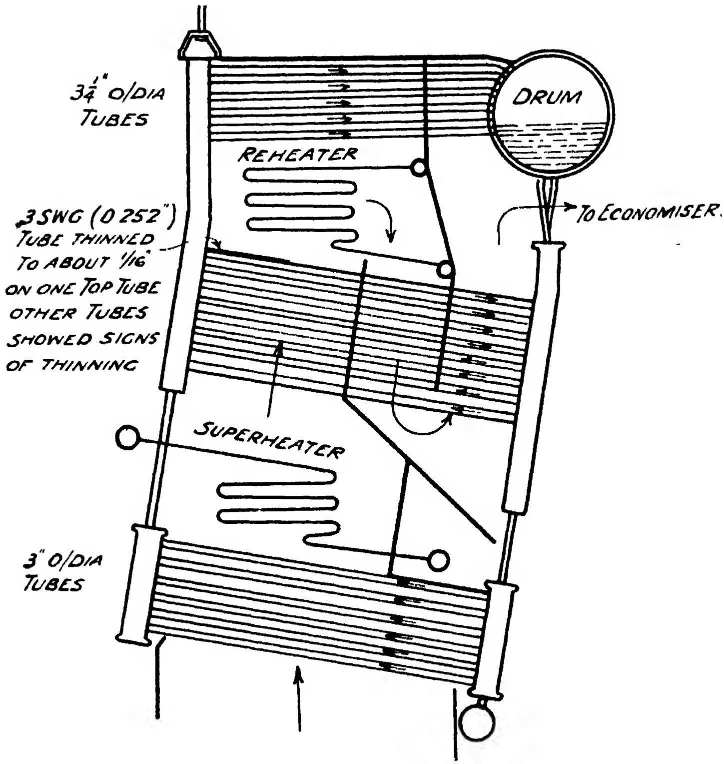


FIG. 128. Straight Tube Boiler.

of cutting out and welding in new pieces. The trouble is commonly termed steam pocketing and in time results in a thinning of the upper tubes by corrosion due to oxygen formations at the higher ends of the tubes. It would appear that this trouble may be due to or aggravated by one or more of the following :—

(1) Restriction of steam release from tubes to drum.
(2) Overloading of boiler for extended peaks.
(3) Oxygen content of feedwater.
(4) Chemical treatment of feedwater (excessive or too weak).

(5) Incorrect water levels.
(6) Condition of tubes—both inside and outside.

What is known as counter or reverse flow takes place in these tubes, the extent of which is difficult to determine. A slight amount will interfere with the steaming capacity and flexibility of output due to poor water circulation and steam pocketing. Under these conditions the water gauge readings will be erratic due to turbulence in the drum as under these conditions circulation is short-circuited. There is usually some evidence of overheating in the bottom tube rows and about the middle of the front header sections, just below the bottom tube rows of the upper deck tubes, as the result of impaired water circulation and steam pocketing.

Nipples may be fitted in the water supply ends of the affected tubes to prevent back-flow in the tubes. Only a small orifice is required to supply water to these upper tube rows and this also restricts any tendency to a free discharge if oxygen formations occur at the higher ends of the tubes. Fundamentally, it is a question of static head in the downcomer tube and if this head of water is interfered with, such as reduced density (due to steam bubbles entering the tube), normal water movement and steam bubble release is restricted in proportion.

Brickwork, Water Walls and Baffles. The choice of brickwork for the modern boiler is an important item, the types varying according to the positions in which it is used. Brickwork may be broadly divided into two classes, each being required to serve two distinctive purposes :—

(1) To prevent transfer of heat.
(2) To resist high temperature and impingement of flame.

Bricks do not possess both of these qualities, so it is necessary to use two separate bricks.

The principal features to be considered are :—

(*a*) Ability to resist high temperature.
(*b*) Ability to resist abrasion.
(*c*) Withstand accumulation of slag.
(*d*) Withstand all expansion and contraction to be met under working conditions.
(*e*) Uniformity of size.

The soundness of the combustion chamber brickwork depends on the quality of the bricks, workmanship, thinness of joints and operation of the furnace. If a boiler is cooled down too quickly there is risk of damage to the arch.

The boiler walls should be designed and constructed in such a manner and of such material to ensure a minimum of heat radiation into the boiler house and be lined with suitable refractory material, the whole construction of the refractory being such as to ensure the maximum life consistent with the operating conditions of the unit. The brickwork should be finished thoroughly sound and tight to prevent the ingress of air to the boiler setting. Shaped firebricks of suitable quality may be used for combustion-chamber lining. Provision should be made for expansion in each course. The allowance normally required is :

95 per cent. silica	1·25 per cent. linear (3 in. on 20 ft. wall)
Firebricks . .	0·75 per cent. linear (1·8 in. on 20 ft. wall)

The life of a boiler setting largely depends upon the quality of

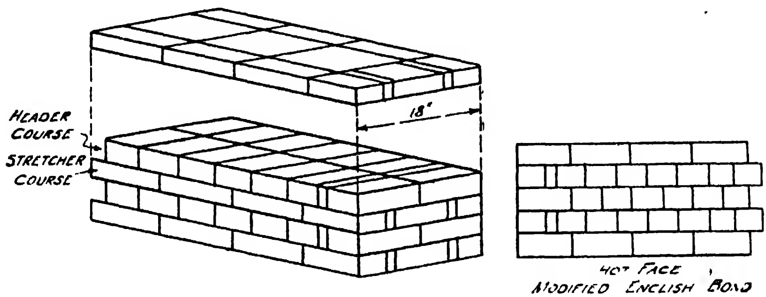


FIG. 129. English Bond.

firebricks used and the manner in which it is laid and constructed. The combustion chamber linings may be laid three stretchers and one header in each course or in Flemish bond. All other walling may be laid in old English bond. The "stretcher" bond is only applicable to a $4\frac{1}{2}$ in. wall. The "header" bond gives perfect bonding on a 9 in. wall and is probably the best arrangement for high temperatures, especially if the load is high on the brickwork , the load can be carried by the cooler ends of the brick where the temperature is lower. For walls thicker than 9 in. the combination of some stretcher courses with the headers is necessary to get a tie or bond throughout the thickness of the wall. Figs. 129 to 131 show bonds.

The "English" bond of alternate courses of headers and stretchers is the most common bond for $13\frac{1}{2}$ in. walls and is also used for thicker walls. The "Dutch" bond is similar to the English bond but gives even better bonding. The alternate stretcher courses are not coincident and this makes it less likely to have

several vertical joints coinciding in a long wall where the bricks may gradually run out of the bond. Whatever method of bonding be adopted the joints should be kept as thin as possible. The bricks should be of a suitable size and true to shape for properly bonding together. Well-burned firebricks are used for combustion chamber linings, the fire clay being finely ground and of the same quality as the bricks. The construction of the combustion chamber should be such as to prevent distortion and deterioration of the brickwork due to the high temperature and loading. Where repairs are unavoidable the brickwork may be of sectional supported construction, thereby enabling local repairs to be carried out without

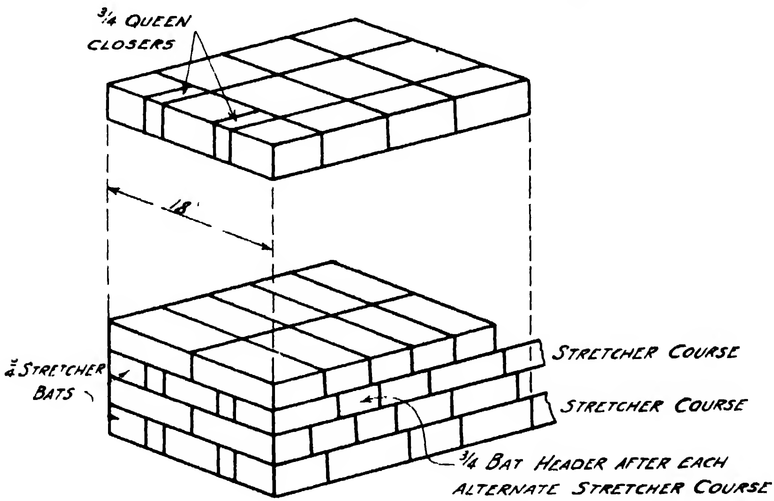


FIG. 130. Dutch Bond.

unduly disturbing the adjoining material. Where finned tubes are used, firebrick soaps or a plastic mixture may be used for making up to the insulating bricks and casings. Both methods have advantages, the former in that it does not impair tube movement due to expansion or other causes whilst the latter facilitates tube removal without affecting the brick structure. After the plastic mixture is placed in position it sets very hard, becoming one mass of refractory, and prevents expansion of the fins and tubes. If a tube has to be replaced when soaps are used then the entire length of the soaps associated with that tube have to be taken down. The removable casing plates help to overcome this difficulty.

Water walls were outlined under "Combustion Chamber." The area of the water-cooled walls and water screens should be such

that the temperature of the combustion chamber is limited so as not to affect adversely the brickwork and also prevent the fusing of the ash when the units are operating at high loads and high efficiencies. The circulating system in the water walls should be positive and the tubes which are exposed to the full heat of the combustion chamber should at all times be filled with water and steam pocketing must be avoided. The water wall blocks are set on all faces and around tubes with a good quality setting material. A high conductivity refractory cement between tubes and blocks ensures rapid transfer of heat and adequate protection of the refractories. In some boilers the combustion chambers are clothed

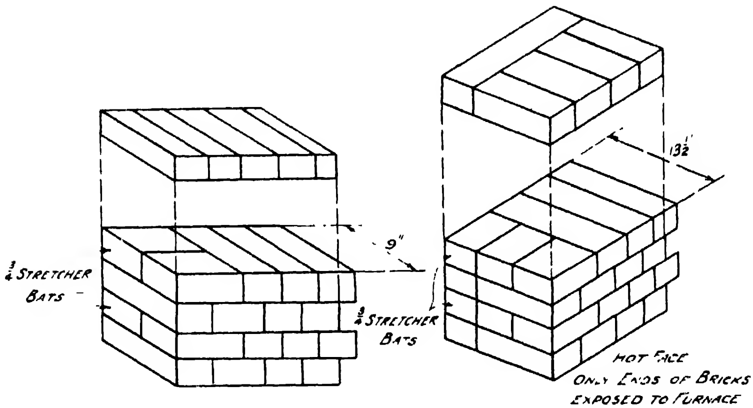


FIG. 131. Header Bond.

with refractory tiles throughout, the tiles fitting close on the tubes which are self-locking.

Combustion chamber water wall constructions vary and combinations of the different types are found in practice. The most common forms of construction are :—

(1) Bolted block construction of smooth cast-iron blocks.
(2) Bolted block made up of cast-iron blocks faced with refractory.
(3) Plain tubes.
(4) Fin tubes.

The bolted block construction is a combination of the first and second methods. Smooth or bare blocks are used for protection against clinker erosion along the grate level of a stoker, and for the higher portions of combustion chambers where it is desirable to provide a surface that will absorb heat at very high rates and prevent the adhesion of ash particles. The ingress of moisture

between the blocks and tubes may result in electrolytic action and corrosion.

Plain tubes are used in both pulverised fuel and stoker-fired units. The front, side and rear walls of the combustion chamber for a stoker-fired unit may be protected by water walls of part cast-iron block and part plain tube construction. The protective metal blocks are fitted on the tubes to a reasonable height above the stoker. The height would vary according to whether a chain grate or retort stoker was used.

In some designs the side walls are built in two sections, the bottom section being arranged parallel to the grate and completely protected by cast-iron blocks. Situated immediately above this section is a water screen of plain tubes (slag drip), which enables the slag from the side walls to fall clear of the bank of protective blocks and drop on to the grate.

Fin tube walls are used on both stoker and pulverised fuel units. The fins may be welded continuously or in short lengths. Troubles due to cracking of fins, material stresses and corrosion have been experienced with this type of construction.

The system of baffles and deflectors should be such as to direct the flow and maintain the speed of the gases over the tubes to ensure correct heat transfer. The baffles and deflecting tiles are held in position on suitably arranged supports. Fire-brick and cast-iron baffles are used. All baffles should be maintained in a perfectly tight condition.

Supporting Structures, Casings and Insulation. The boiler unit and its integral parts should be carried or hung on its own independent steel supporting structure and have no connection with the building. The supporting structure is external to the casing, being designed and arranged to avoid the possibility of damage by excessive heat. The unit is supported independently of any casing or brickwork, provision being made for expansion and contraction. The entire unit is enclosed in a dust- and air-tight mild steel casing constructed to facilitate removal and prevent accumulation of dust. The casing is designed so that it is unaffected by expansion and contraction of the boiler or combustion chamber pressure parts, thereby obviating the possibility of leakage. All casing joints have a non-rubber content asbestos strip. Various types of heat-insulating materials have been used for lining the casings, usually in the form of slabs or mattresses.

In some types a stagnant air space is formed between the slabs and the casing plates to ensure good heat insulation.

The necessary access, observation and lighting-up doors and all connections for the reception of soot blowers and instrument points are provided. The boiler drums and all other parts which are exposed to atmosphere are covered with heat-insulating materials of appropriate thickness and composition. The covering on boiler tops and drums have good wearing properties to withstand walking on. Sheet lead has been used as a protection on boiler drums.

For particulars of heat insulation, reference should be made to "Pipework," Chapter VIII.

Platforms, Galleries and Stairways. The types and capacities of steam-generating units have resulted in a considerable increase in the heights of such units, which in turn has necessitated the use of a well-planned scheme of access stairways, platforms and galleries. These provide access to all mountings, instruments and integral parts in order that operation, inspection and maintenance may be carried out expeditiously. The platforms should extend to each adjacent boiler and all end and side walls, so forming, as far as possible, continuous floors between and around the boiler units. There should be ample floor space at each level, and this is possible by omitting light wells. Some floor space, however, must be sacrificed due to the necessity of providing sufficient headroom for the stairways leading to other levels. Although this flooring entails additional cost it is fully justified by its usefulness to the operation and maintenance staffs. Steep stairways should be avoided wherever possible, as they are very fatiguing. The slope should be gradual and in any case not more than 40° from the horizontal. Operatives should be able to go direct to a similar unit of plant on an adjacent boiler without diverting from the same floor level or having to walk round machinery and galleries. Some form of grid flooring made from steel strips on edge and welded together is quite satisfactory. By extending the flooring close up to the boiler casings it is possible to eliminate handrailing, since it prevents operatives accidentally slipping between the flooring and the boiler units. Slots have to be cut out in the flooring to permit the many steam and feed pipes, etc., to pass to various levels. Handrailing should be neat and of robust construction. To facilitate withdrawal and removal of plant certain sections of the flooring and handrailing must be removable.

Ash, Riddlings and Soot Hoppers. The design and construction of the main ash hoppers depends on the method of firing, *i.e.*, stoker or pulverised fuel, and the type of ash-handling plant installed. Steel plate lined with refractory fire bricks or tiles is usual. The

design is such that the ashes may be discharged continuously or intermittently to the handling plant. The capacity depends on the storage required.

With low-pressure sluicing and immersed scraper conveyor systems the ashes may fall continuously into the water troughs. A cast-iron grid may be fitted over the trough. In high-pressure water systems the discharge of ash to the troughs is regulated to avoid choking and means are provided for effecting this. Quenching nozzles are incorporated in the upper portions of the storage hoppers to render the ash cold and free from dust. To guard against the corrosive action of water which has been in contact with ash, unmachined cast-iron plates are used, as iron castings in their untreated state have a protective skin.

If the quencher supply fails the possiblity of overheating the hoppers is overcome by providing a lining of refractory fire bricks or tiles.

At every three or four courses of bricks ledges are cast on the inside of the hopper, and in this way brick failure does not cause complete collapse of a wall. The chutes from the hopper outlets have a by-pass door so that the ash may be discharged on to the floor of the basement in case of handling plant failure. In some designs two doors are included, one serving as the emergency outlet and the other for preventing discharge to the sluiceway.

The double door arrangement necessitates two operations, to close off the discharge to the sluiceway and to open up discharge to the basement floor. With such an arrangement it is possible that the first operation may be effected without the second operation taking place and the discharge of ash is not fool-proof and may result in building up of ash in the hoppers to the underside of the crushing rolls or dumpers. A single door may be used, which simplifies construction and use can be made of a robust and simple form of door operating gear such as a worm and worm segment mechanism with ratchet spanner.

Door troubles are sometimes experienced. The fine ash, mixing with the vapour rising from the trough, is deposited and hardened on the operating gear (which is usually in the form of a rack and pinion on slides) and causes jamming. This is a point of importance, particularly with the double door arrangement. Hopper door design should receive special attention owing to the arduous conditions under which they are required to operate. Failure of operating gear may result in large quantities of ash accumulating in the hopper pits or chutes and will impose considerable load on the gear.

It may be necessary to provide access doors in the hoppers and chutes to facilitate cleaning, and these should be of adequate proportions.

The riddlings or siftings hoppers are of much lighter construction than the ash hoppers, the lining varying with the type of stoker used. Vertical portions have slab insulation with non-conducting heat-resisting composition, whilst sloping portions have plastic insulation with a layer of refractory tiles bedded on top and jointed with fireclay. The larger hoppers have a door to give access to the wind-box. An outlet gate is fitted on each hopper which is operated from floor level. The basement should be kept free from all dangerous projecting rods, levers, handles, etc., which hinder the movement of operatives. This applies in particular to hopper outlet operating levers and a chain-operated sliding screw gate is quite suitable.

The riddlings or siftings, the quantity of which is small, usually about 0·05 to 0·10 per cent. of the coal fired, should be observed at discharge for two reasons :—

(1) To ensure that the hoppers are emptied.

(2) Examination of the riddlings discharged will give good indication of the correct mechanical operation of the grate.

The riddlings chute can be designed to meet these requirements by fitting a by-pass door and small chute to permit of alternative discharge to a bogie or the basement. The normal discharge can be to the ash-handling system.

Like the ash and riddlings hoppers the number and size of soot hoppers will depend on the capacity of the boiler, and with boilers of similar capacity, manufacturers have different ideas regarding both number and size. Pockets should be eliminated to avoid any accumulations of soot or other deposits. The economiser and boiler soot hoppers require lining with refractory tiles or bricks, but those on gas ducts and precipitators are generally left unlined.

Access to each hopper should be possible by a conveniently placed door of adequate proportions. To facilitate clearance of an outlet stoppage due to pieces of brickwork or insulation a number of poke-holes should be provided in each hopper and companion compartment. The soot and flue dust is extracted from the hoppers by vacuum extraction plant whilst the boiler is in operation. Special valves are fitted to the hopper outlets for this purpose.

STOKERS

A stoker should not only be designed from the combustion point of view, but it must also be mechanically strong to withstand all

working stresses due to high temperature, etc. A sound and simple design will ensure low first cost, minimum maintenance and operation for long periods without failure. Some of the factors to be aimed at in stoker design are : maximum rates of burning, highest continuous efficiency and the unlimited choice of fuels.

Any study of the use of stokers must commence with an analysis of the four principal constituents of coal, namely, moisture, volatiles, fixed carbon and ash, or more generally, water, tar, coke and dirt.

These determine the features which should be embodied in the stoker and furnace equipments so that proper treatment of the coal at the correct time is effected on its passage through the furnace. Apart from the analysis and calorific value the properties of coal which affect combustion are : the size distribution for which perhaps the most quoted figure is the percentage passing through a $\frac{1}{8}$ in. sieve ; the agglutinating value, which is a measure of the capacity of the particles to bind together when heated, and the percentages of sulphur and phosphorus, the first because the burning of sulphur produces fumes which should be eliminated from the flue gases where deemed necessary before passing to the chimney and the second because this constituent may affect the boiler-tube fouling in certain forms of firing. In order to maintain high efficiency it is necessary to ensure that the following are in good condition : ash plates and dumping bars, sealing plates at side of stoker, brickwork of arch and curtain and feedbar.

Whichever type of stoker is used the coal has to be taken from the bunkers to the feeding hoppers on the boilers. The coal falls by gravity from the bunkers through a valve into feeding chutes. In some installations automatic weighers are included in the downspouts between the cut-off valves and the boiler feed hoppers. The cut-off valves may be operated from the firing floor by means of chains. A good arrangement is to let the chains hang down to about 10 ft. above floor level and provide operating poles. The chutes are one of two types, namely, traversing and fixed. The former are designed to meet the large width of grates now in use, as the fantail rectangular box type chute which spreads uniformly from the bunkers to the feeding hopper is unable to provide a sufficiently even distribution of coal. A special design of fixed chute is in use which is non-segregating. It contains portions of cones on to the apex of which the coal is fed from the bunker chute. Perfect distribution and even feed of coal across the full width of the grate is claimed, but traversing chutes appear to be better even for retort stokers. There are usually two or three chutes for large boilers. The traversing

chutes travel the full width of the feeding hopper, the motion being effected by means of a continuously rotating screwed shaft which engages with a special nut attached to the chute. The operating shaft has right- and left-hand helical grooves and the nut is designed so that at the end of its travel it reverses automatically. The speed of the carrier is about 4 to 5 ft. per minute, and the minimum time for the chute to travel across and back would be approximately four minutes. The chutes are operated from the stoker drive, there being two or four chutes for large boiler units. Coal chutes are of welded mild steel plates, wearing plates also being included. The chutes may be lined with vitrified steel plates to prevent rapid wear and tear. Due to shortage of coal or local conditions it may be desirable to use a proportion of coke or coke breeze. Special mixing bunkers will be necessary but at the best permanent mixing is difficult and restricts the use of coke. A double chute arrangement is possible, one for coal and the other for coke.

In one station, due to low-grade coal (9,000 B.Th.U. as fired, 22 per cent. ash, 20 per cent. volatile), provision was made to instal hopper screening gear on the stokers if found necessary. This provides for a layer of fines to be superimposed on a layer of peas on the grate and so promote early ignition.

The use of coke breeze on retort stokers is limited and appears to be only suitable at easy loads up to economical rating. It is found that the coke breeze is blown off the tuyeres towards the back end and much of it is deposited in the crusher pit which may lead to burning and damage to the crusher rolls.

Another disadvantage is that coke is very abrasive and causes considerable wear on the I.D. fan runners and casings, etc. The stokers are one of two classes, overfeed chain grate or underfeed multiple retort type.

Chain Grate Stoker. This is the most common type, the forward motion of the grate carries the coal from the hopper at the front end, thereby controlling the flow on to the travelling grate. This hopper has a reasonable capacity and is fitted with a cut-off gate which extends the entire width of the grate. The primary function of this gate is to control the flow of coal to the grate, but in addition it gives access to the furnace during banking and similar operations.

An index plate with pointer indicates the thickness of coal bed at all times and this may be regulated by adjusting the opening of the doors on the furnace front. Further control of combustion is obtained by speed control of the stoker driving motor. For very large boilers twin grates are used. The travelling-grate stoker, which

has evolved from the original chain grate stoker, utilises a grate surface which is carried round by the chain, but is an independent structure so that it can be designed with a view to combustion efficiency and good clearing of the ashes rather than be hampered by the necessity of carrying mechanical loading stresses at the same time. The design and construction of the grates has received special attention, the linking arrangement in particular (Fig. 132). The links are made from heat-resisting cast iron designed to minimise breakage. The grates are sub-divided by the use of sectional linking, each section being built up of a common type of link

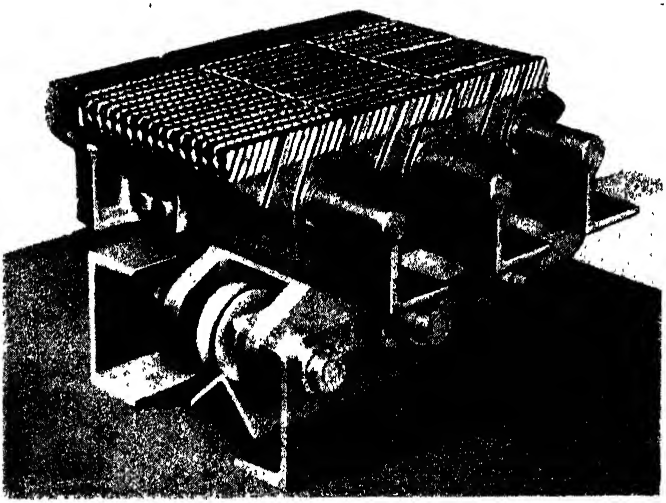


FIG. 132. Grate Fire Bars and Bulb Angles with Rollers and Guides. (Bennis Combustion Ltd.)

which forms the greater portion of the grate surface. The sides of the links are serrated which gives the grate a large air spacing without an excessive space between individual links. This reduces the quantity of riddlings or particles of unburned coal which fall between the links of the grate into the air boxes below to about 0·5 per cent. of the total coal fired. Coal bridges over the top of the serrations and air can pass along the grate surface and so reach all parts of the coal-bed. It is claimed that this type of link has the advantages of uniform distribution of the air to the coal, reduces riddlings passing through the gate, low percentage of carbon in the ash, high rates of combustion, large area of metal is exposed to the cooling action of the air passing through the grates,

and movement of the links relative to each other prevents the air spacing being choked with ash. The edges of the grate are sealed against air leakage by overlapping side links. In this way the damage to the brickwork and clinkering of the side walls which may be caused through excessive air leakage is prevented.

The air supply above and below the grate is of prime importance and it is usual to divide the underside of the grate into several compartments, each of which are connected to the air duct or wind box through adjustable dampers. The arrangement is such that the air pressure from the forced draught fans is a maximum in the first compartment and is successively reduced in the remainder. The reduction in air pressure or draught is approximately proportional to the thickness of the coal bed on the grate above. The air distribution valves are so arranged that all the valves in each row are operated simultaneously. The valve arrangement is such that any fine dust or riddlings which may fall through the grate can fall straight through the valve opening without any possibility of holding up. Some stokers have a fan for delivering cold air over the return half of the grate to cool the lower half and so reduce maintenance and combustion troubles. If the temperature of the grate gets out of control trouble may be experienced from "cauliflowering."

At the front end of the grate the raw coal undergoes a process of coking and it is here that the volatile hydrocarbons are driven off and combustion of the resulting gas can be effected by deflecting them downwards on to the incandescent coal further back. To meet this requirement it is usual to provide a low ignition arch and in addition combustion may be further assisted by including a supply of secondary air through nozzles in either the front or rear arches of both. Arches of various forms have been tried. The three chief functions of arches are :—

(1) To ignite the coal.
(2) To direct the flow of gases to the heating surface.
(3) To ensure proper mixing of the furnace gases.

The arches are subjected to severe working conditions and the ordinary brick-built arch is not suitable as it lacks strength and the ability to "breathe." The construction adopted to meet these conditions consists of strong steel joists from which are supported steel hanger beams, the latter holding in position specially formed small refractory blocks. These small blocks in turn hold deep section refractory blocks and is referred to as a suspension arch. The double arch construction has been used but in this case the intensity of draught is stepped upward from front to rear, being

greatest where the coal bed is thinnest. From the front end of the grate a large volume of rich gas rises slowly and meets the hot quick-moving gas from the rear end, resulting in thorough mixing and ignition in the furnace throat. In some designs the front arch is practically eliminated whilst in others both arches are employed and the angle of inclination of the walls increased. In a number of designs stokers have been set within square walls in the combustion chamber without an arch. Fires are usually burning several feet from the dumper noses and if "conditioned" coal is used the ash on the dumpers will generally be of a small nature. The coal is sometimes "conditioned" by watering before entering the boiler bunkers and a further advantage is that "tailing" on the fires is avoided although this also depends to a large extent on the characteristics of the coals burned. The travelling grate carries the ash along to the rear of the combustion chamber and then dumps it into hoppers.

Stoker ratings may vary from 30 to 50 lb. per sq. ft. per hour and where lower grade slacks containing a high proportion of "fines" (particles under $\frac{1}{8}$ in. sizing) are burned the additional capital cost of installing boilers with stokers at the lower ratings is often justified.

The grate is driven by worm reduction gears and electric motor. For large stokers independent gear boxes are provided which are direct coupled to stokers by means of flanged couplings. The boxes have a spring-loaded slipping clutch and all the internal moving parts run in oil baths. The boxes may be designed for wheel mounting, thereby avoiding floor fixings beyond a safety saddle piece fitted on the rear wheels. Variable speed motors are sometimes used for speed regulation but constant speed squirrel cage motors with gear boxes having eight speeds are quite suitable.

Spreader Stoker. In spreader or sprinkler stokers the coal is handled by the revolving blades of feeder units and flung out into the furnace on the top of the fire, the smaller particles burning in suspension as they pass through the flames. This type is now in service in this country for units up to 250,000 lb. of steam per hour. Although pulverised fuel firing is established in a good position by virtue of the high availability it offers when compared with travelling grate stoker firing, there is a field in the smaller and medium size of unit in which types of firing appliances handling raw coal can successfully operate. The spreader stoker has been widely adopted in the U.S.A. The travelling grate is usually arranged to move towards the front of the boiler, which has the advantage of giving larger particles more time for com-

bustion, the speed of the grate being much slower than that of the normal travelling grate stoker, which is a function of the amount of coal being burned. The choice of this stoker for one station was influenced largely by the difficulty of obtaining uniform quality and grading of slacks suitable for the operation of chain grates. It was considered that this stoker would be more adaptable to the fluctuating and poor qualities of fuel obtainable.

The raw coal which should pass through a 1½ in. ring is delivered to the combustion chamber by a series of feeder units placed across the furnace width. These feeders are at such a height that the trajectory of the coal thrown from the rotor is evenly distributed on the grate and reaches the rear end of the grate. During this process, particles fine enough for burning, ignite as they pass into the flame and burn out in suspension. A large proportion of the coal, however, ignites on contact with the active fuel bed and burns out on the grate. The fuel bed is normally about 1 in. thick and combustion takes place at the surface of the bed. The ash remains below the fuel and both grate surface and ash are maintained at the temperature of the incoming air. This tends to eliminate clinkering even if the fusion temperature of the ash is as low as 2,000° F., and ash on the grate tends to protect the bars.

The feeders are coupled together and driven by one motor and cooling air is applied to those feeder parts which are exposed to radiant heat of the furnace. Since there is very little active fuel in the furnace at any given time, the fire will go out within a few minutes if the fuel supply is stopped, even though the air supply is maintained. This feature makes the spreader stoker very responsive to changes in fuel and air supply and an increase or decrease of fuel with constant air flow, or *vice versa*, will produce a marked change of CO_2 in the flue gases in a matter of seconds.

Efficient operation therefore demands that not only should the fuel and air supply be operated simultaneously, but that they should be varied by correct corresponding increments.

This stoker has been arranged for grit refiring for 300,000 lb./hr. boilers and cyclone burners for greater capacities. Freedom from bonded deposits and flexibility due to very rapid response to changes in rates of evaporation are advantages claimed for this stoker. The very rapid response of this stoker to changes either in air or coal supply necessitate automatic control to obtain best results.

The grate is built up in sections, each of which has its own feeder and the grate travels from the rear of the furnace to the front, *i.e.*,

in the opposite direction to the usual chain grate stoker. Troubles have been experienced with some plants particularly from : boiler fouling (generating and superheater zones) ; superheater tube failures and generating tube thinning ; grate bar breakages ; wastage of Bailey blocks ; Bailey wall tube thinning and feeder mouth refractory wastage.

This stoker is simple to operate, easy to light up and bring into commission, flexible and responsive to load change and capable of being banked and brought up again with low fuel consumption. The first cost of a unit for a given duty is generally about the same as for stoker firing in the smaller sizes and slightly less in the larger sizes. It is considerably less than the first cost of a corresponding pulverised-fuel boiler unit. For medium and large capacity units it is usually necessary to provide some form of grit refiring system.

Retort Underfeed Stoker. The retorts are in the form of troughs of rectangular cross-section with upper edges which are downwardly inclined from the front to the rear of the stoker. As the floor of each retort is inclined in a similar direction but at a lesser angle to the horizontal, the arrangement is such that the volumetric capacity of the retort is uniformly diminished in a rearward direction. The retorts are positioned at regular intervals across the stoker width, and the grate surface proper which occurs between the retorts is supported from, and accordingly has the same inclination as, the upper edges of the retort sides. This grate surface consists of a large number of overlapping plates, each of which has a smooth upper surface and a lower surface which is ribbed longitudinally. The multitudinous orifices formed by superimposing the ribbed lower surface of each plate on the smooth upper surface of the plate immediately below, along the full length of, and between each adjacent pairs of retorts, provides the means for the admission of air. These plates are known as " tuyeres."

The coal hopper is placed laterally across the stoker front and receives its coal supply through downspouts and chutes from the bunkers. The primary rams which reciprocate horizontally take charge of coal from this hopper and force it through entrance throats into the upper ends of the retorts.

A number of secondary rams or pushers, which also have a horizontal reciprocating motion, are positioned in the floor of each retort. The first of these receives the coal as it passes from the primary ram and forces the coal down the retort to the second pusher, which in turn forces the coal still further down the retort and

so on, the number of pushers in each retort being a function of the particular length to which the retort has been built.

Combustion can only take place above the level of air admission, *i.e.*, above the tuyere plates and the upper edges of the retorts. It follows therefore that the coal can only enter the fire from below, that is to say, it is underfed. The assistance which the stoker mechanism receives from gravity in the propulsion of the coal bed can best be understood from an appreciation of the fact that the weight of coal is supported more particularly on the retort bottoms, which have an angle of some 20° to the horizontal. The pushers reciprocate in a horizontal direction and consequently the greater the inclination of the retort bottom the more effective will become the incidence between the pusher and the coal bed. The angle of 20° referred to is that which experience has proved to provide the most effective incidence between pusher and coal bed without disrupting the structure of the fire, and it is also that which allows the influence of gravity to operate to the fullest practicable degree in actuating this coal bed in conjunction with the forward movement of the pushers. Each distributing pusher is adjustable (generally short stroke for dry coal and long for wet coal) from the front, thus giving complete control for maintaining the requisite fire surface contour and coal-bed thickness throughout at all loads, whatever the characteristics of the coal. Air enters the tuyeres from the wind box below and issues through multitudinous orifices, horizontally into the coal bed, so ensuring an intimate mixture of oxygen and combustible matter. High-pressure secondary air has been used with this type of stoker and two secondary air fans may be fitted. Care is essential in the operation and maintenance whilst good working conditions are also influenced by the classes of coals used. Under certain conditions it is possible to form huge clinkers and unless care is exercised damage to the pushers is unavoidable whilst the grate may also be severely burnt. The only way to remove such clinkers is to burn off the fire as soon as it is convenient and after the chamber has cooled so as to permit of men entering, then the clinkers can be broken up. The retorts and tuyeres are protected from damage by a layer of green coal, yet it is possible to regulate the air supply to such a degree that a very high furnace temperature is maintained and the CO_2 content of the gases leaving the combustion chamber can be kept fairly high at all ratings.

The range of the feeding gear and variable speed drive combined with the reserve in the deep bed of coal makes it possible to cater for wide and rapid fluctuations of load. There is no necessity for

any quenching of the ash, and the large mass of clinkers and ashes in the pit and the arrangement of crushing and extracting gear form an effective seal to the furnace. The large clinkers from these stokers make it impossible for sealing plates to be fitted in the water troughs.

The rotary ash discharge system consists of a pit with two rolls at the lower end, the rolls being provided with crusher teeth. The rolls rotate outwardly and in opposite directions, thereby crushing the clinker against adjustable aprons and discharging it to the hopper below. The clinker crushing and extracting rolls are driven through gears by electric motors of the squirrel cage constant speed type.

Ash of reasonable size is used to fill the pit before lighting up.

The stoker drive may be a constant speed squirrel cage motor in conjunction with a hydraulic variable speed transmission, giving a speed range of about 30 to 1, and which is capable of operating continuously and reliably for long periods at any speed within this range. This drive appears to give better control of firing conditions than does the commutator motor drive. A variable speed a.c. commutator motor is sometimes adopted which obviates the use of hydraulic transmission gear. Occasional reversing of the motor is required to free any obstruction which may foul the mechanism and cause the shearing pins to fail. Table 24 gives comparative details of chain grate and retort stokers.

TABLE 24. *Chain Grate and Retort Stoker Details*

Boiler Capacity and Type of Stoker	150,000 lb. per hour N.E.R. and 187,500 lb. per hour M.C.R.	
	Chain Grate	Retort
Length of grate	18 ft. 6 in.	19 ft. 8 in.
Width of grate	26 ft. 0 in. (twin)	26 ft. 3 in.
Projected grate area, square feet	472	515
Number of retorts	—	15
Number of tuyeres per retort	—	49
Type of speed reduction gear	8-speed gear box	2-speed gear boxes, A.C. variable speed commutator motor.
Thickness of fire, N.E.R.	6 in.	18–24 in.
Thickness of fire, M.C.R.	6 in.	18–24 in.
H.P. of stoker motor	3½	8/2·67
Number of stoker motors	2	1
Speed of stoker motor, r.p.m.	960	1,440/480
Speed of crusher rolls	—	1 rev. in 55 mins.
H.P. of crusher motor	—	10
Number of crusher motors	—	2
Speed of crusher motor, r.p.m.	—	720
Total weight of complete stoker, tons	95	136
Comparative cost	1·0	1·2

SUPERHEATERS AND DESUPERHEATERS

Superheaters raise the steam from saturation temperature to a final temperature of from 750° to 1050° F. and to obtain satisfactory control of the steam outlet temperature many boilers are fitted with two superheaters, a primary and a secondary and a desuperheating equipment.

When a superheater is designed for a given input of dry steam a very small quantity of water will lower the superheat appreciably. Assuming a pressure of 200 p.s.i. and entering steam to be 2 per cent. wet. Latent heat of steam at this pressure = 800 B.Th.U./lb. Number of B.Th.U. required to dry the steam $= \frac{800.2}{100} = 16$. Specific heat of dry steam at this pressure = 0·75, then superheat will be lowered by 16/0·75 = 21° F. approximately.

A superheater consists of an inlet and outlet header between which are connected a number of small diameter U-shaped tubes in parallel or series. The tubes or elements may be of single or bifurcated construction, the latter reducing the number of joints required.

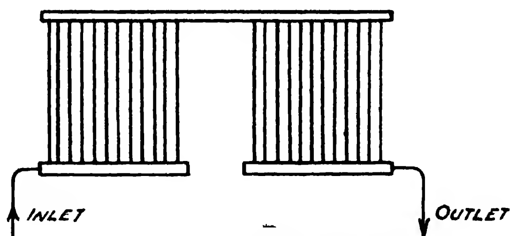


FIG. 133. Two-pass Superheater.

Each comprises two steam paths in parallel, joined at the ends to common inlets and outlets. Superheaters may have two or more passes across a boiler, Fig. 133, but current practice appears to favour the single-pass superheater. When a superheater consists of a number of passes across a boiler there is a difference in temperature of the gases leaving the various passes, and this may have a detrimental effect on the performance of the boiler, economiser and air heater. From operating results it is noted that the difference in gas temperature leaving the superheaters is almost negligible. The superheater elements are attached to the headers by means of clamped metal-to-metal ball joints held in position by forged clamps and steel studs ; hand-holes are unnecessary and it facilitates easy fitting and removal of elements and reduces the number of joints. Special joints are used for very high pressures, and temperatures of over 750 p.s.i. and 800° F. (Figs. 134 and 135). By using return bends multiple loop superheater elements of any desired length may be

fabricated. With the multiloop arrangement, the desired degree of superheat may be obtained with a single-pass superheater built up of many elements all connected in parallel between two headers.

FIG. 134. (Superheater Co. Ltd.)

The elements are fitted with heat-resisting steel bands welded into position, the inlet and outlet legs of each being fitted with an adjustable supporting sleeve and washer. The main supports are placed outside the boiler and usually comprise angle sections studded to the underside of the superheater headers. The elements inside the boiler setting have heat-resisting iron spacers and strap bolts and nuts of heat-resisting material. The inlet and outlet headers are fixed on roller supports mounted on steel beams. The arrangement of the flow of steam through the superheater tubes affects overheating, the tube temperature being lowest when saturated steam first flows down the front bank of tubes and afterwards up the back row of tubes. If saturated steam first enters the back row of tubes, then the steam at its

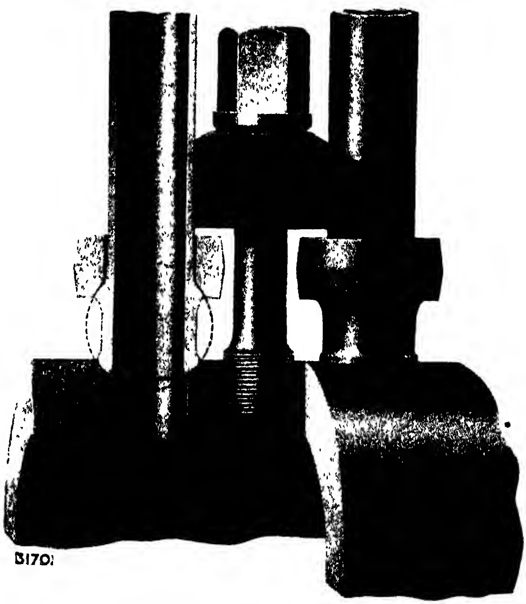


FIG. 135. (Superheater Co. Ltd.)

lowest temperature meets low temperature gases. The steam in the front banks of the tubes is also at a higher temperature when the gases outside are at a higher temperature. The tubes of this front bank, under such conditions, will be at a higher temperature than the tubes at the back of the bank. This arrangement of flow conduces to obtaining the highest superheat. The use of small strong tubes minimises damage due to overheating. The strengths of materials at high temperatures depend on their creep properties, for at a metal temperature of about 900° F. ordinary mild steel commences to oxidise on the inside of the tube in contact with the steam. This oxidisation results in the formation of a heat-resisting crust which impairs heat transmission and encourages high local metal temperatures.

Mild steel is suitable for metal temperatures up to about 925° F. (steam temp. 850° F.), and 0·5 per cent. molybdenum steel is used for metal temperatures of 925 to 960° F. (steam temp. 850° to 900° F). To ensure protection the superheater elements should have a reasonably high steam velocity, by designing the superheaters with sufficient pressure drop. Superheaters designed in accordance with the following have proved satisfactory :—

Boiler output 187,500 lb. per hour. M.C.R. 40 p.s.i. drop.
,, ,, 130,000 ,, ,, ,, 17 ,, ,,

It has been demonstrated that theoretically the maximum stress in a bend of uniform thickness is not on the outside but on the inside. This is offset in practice by the thickening of the metal which takes place on the inside of the bend and many bursting tests confirm that the close radius bends are actually stronger than the straight tubes from which they are made. Failures have usually occurred in the straight portion rather than in the bend.

Superheaters for two-shift operation are preferably of the horizontal self-draining type with a damper controlled by-pass and 30 per cent. of the heat input at continuous maximum rating can be applied to the furnace in the second stage. For base-load stations a combination of the pendant secondary and horizontal self-draining primary is most suitable. With primary and secondary superheaters of the pendant type the heat input is limited to about 16 per cent. of the maximum continuous rating and entails intermittent firing. Pressure raising following a thirty-hour bank may vary from ninety (with gas by-passing) to 240 minutes, depending on the type of superheater.

Fig. 136 shows an arrangement for the protection of the

superheater during pressure-raising, banked, or light load conditions.

Considerable thought has been given to the control of steam temperature to protect the superheaters and turbines against unavoidable rises which may take place. Where convection superheaters are installed integrally so that all the gases pass over the heating surfaces, the steam temperature rises with increasing load and in the absence of any appreciable increase in moisture content of the steam will attain its maximum at peak load. The

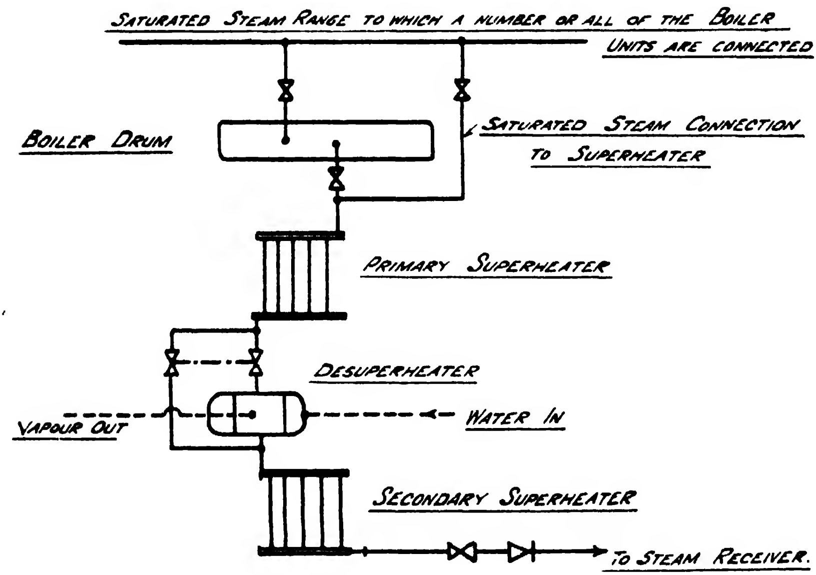


FIG. 136. Saturated Steam Connections for protection of superheater during pressure raising, banked or light load conditions.

rate at which steam temperature rises as load increases depends upon the position of the superheater in relation to boiler heating surface. As the proportion of heat transfer due to radiation diminishes, and that due to convection increases, so the superheat-load curve becomes steeper (Figs. 137 and 138). Convection superheaters are therefore placed in a high temperature gas zone where the ratio of radiation to convection transfer is high. The dimensions of the superheaters are also kept within reasonable limits. For similar reasons combined radiant and convection superheaters may be used, but a suitably placed convection superheater will give equally good results. The intertube and interdeck superheaters

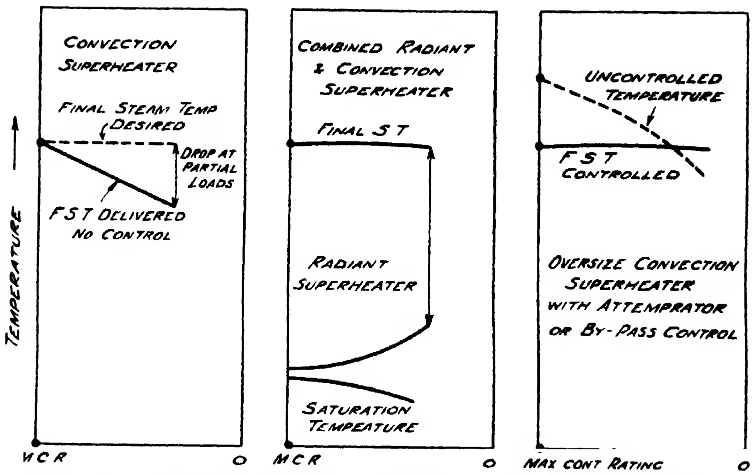


Fig. 137. Typical Temperature Characteristics of Convection, Radiant and Combined Superheaters.

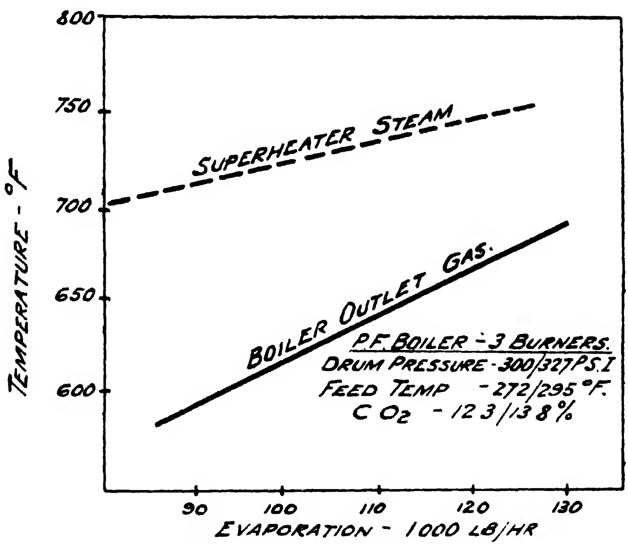


Fig. 138. Superheater Performance.

which are preceded by a small amount of boiler heating surface are typical examples. Methods of superheat control are :—

(1) Dampers in the gas path.
(2) Control of the steam temperature within the superheater.

(3) Combining radiant and convection superheaters in series, enabling inherent superheat control to be obtained.

(4) In pulverised fuel boilers by effecting steam temperature control entirely by the use of tilting burners.

(5) Gas recirculation from the economiser into the combustion chamber has been suggested as a way of contrölling superheat temperature at times of light load.

With gas by-passing it is possible to vary the amount of furnace gas passing through the superheater.

The second method has been developed by the Superheater Company Ltd., which incorporates a desuperheating equipment. It is claimed that complete control can be ensured by the use of primary and secondary superheaters and intermediate desuperheating. On the surface type attemperator, a proportion of the steam leaving the primary superheater is led through tubes immersed in water, either in the boiler drum, or in a separate vessel connected with the drum, so that the heat abstracted from the steam is returned to the boiler water. A thermostatic control operates a by-pass to vary the proportion of steam which passes through the attemperator. In the spray type attemperator, a water-spray is injected into the steam, which gives up some of its superheat in causing evaporation of the spray. This method necessitates increasing the superheater heating surface by an amount which depends upon the range of evaporation over which control is required, the design being such that the final temperature is reached at a predetermined intermediate load. After this an increasing proportion of the steam passing from the primary elements to the secondary elements of the superheater is diverted through the desuperheater. By this means excess superheat is absorbed and the steam produced is returned to the boiler. This, in effect, is equivalent to bringing an increasing amount of steam generating surface into operation as the load on the boiler rises. The control of steam temperature by means of desuperheating compensates not only for the effect of changes in the rate of evaporation, but also for all other variable factors which influence the degree of superheat obtained at any time as distinct from the average figure obtaining at a particular load. The most important of these are :—

(1) Condition of heating surfaces affecting heat transfer.

(2) Amount of excess air for combustion.

(3) Rate of water feeding.

(4) Temperature of feed water. (Reduced feed temperature results in increased superheat.)

(5) Rapid fluctuations in steam demand.

(6) Fineness of grinding in pulverised fuel plants. (Coarse grinding increases temperature.)

(7) Soot blower operation.

(8) Boiler drum water level and concentration.

(9) Slagging up of ash pit screen tube wall.

A combination of these influences might easily result in an increase of 50° F. in superheat and such excess temperature is undesirable where the operating figure is already a maximum. Controlled superheaters render final steam temperatures independent of the varying degree of cleanliness of heating surfaces. As these surfaces become dirty the load at which control comes into operation will be higher, but where the designed range is ample for the particular conditions of load, steam temperature will remain constant throughout for long periods of working. Decreasing the feed water temperature in a boiler increases the superheat for a given output, *e.g.*, a reduction from 450° to 350° F. would probably result in a 40° increase in superheat and a 70 per cent. increase in heat input. Such changes would therefore affect the temperatures throughout the unit. The desuperheater or attemperator used in conjunction with controlled superheaters comprises a forged steel shell and cast steel base complete with elements, with flanges for steam and water services. The elements are made from solid hot-drawn steel tubes, expanded and bell-mouthed into a tube plate of cast steel. By increasing the heating surface in the primary superheater, the heat transfer per square foot of desuperheating surface is increased, thus reducing the size of desuperheater. Increased superheater surface and a desuperheater, together with additional piping, valves and control are necessary which entail higher capital cost. This is considered justifiable due to the saving accruing from reduced steam consumption brought about by the steam temperature being maintained constant regardless of variations in boiler loading and other operating conditions. Further, positive protection against damage due to excessive temperature is afforded. Desuperheating, largely because of throttling, causes a relatively large loss in available energy, and by the same standard the blow-down system may often be less inefficient than commonly assumed. The radiant superheater (one directly exposed to furnace radiation) gives a falling steam temperature with increase in load, while a convection superheater (located in the gas passes, away from direct radiation) gives a rising temperature with the same conditions. By utilising both types, connected in series, compensation can be obtained. Tilting burners maintain control of steam temperature by altering the

position of the hottest zone of the furnace. The burner tilting mechanism is servo-operated, under thermostatic control.

Automatic Control of Steam Temperature. An automatic system

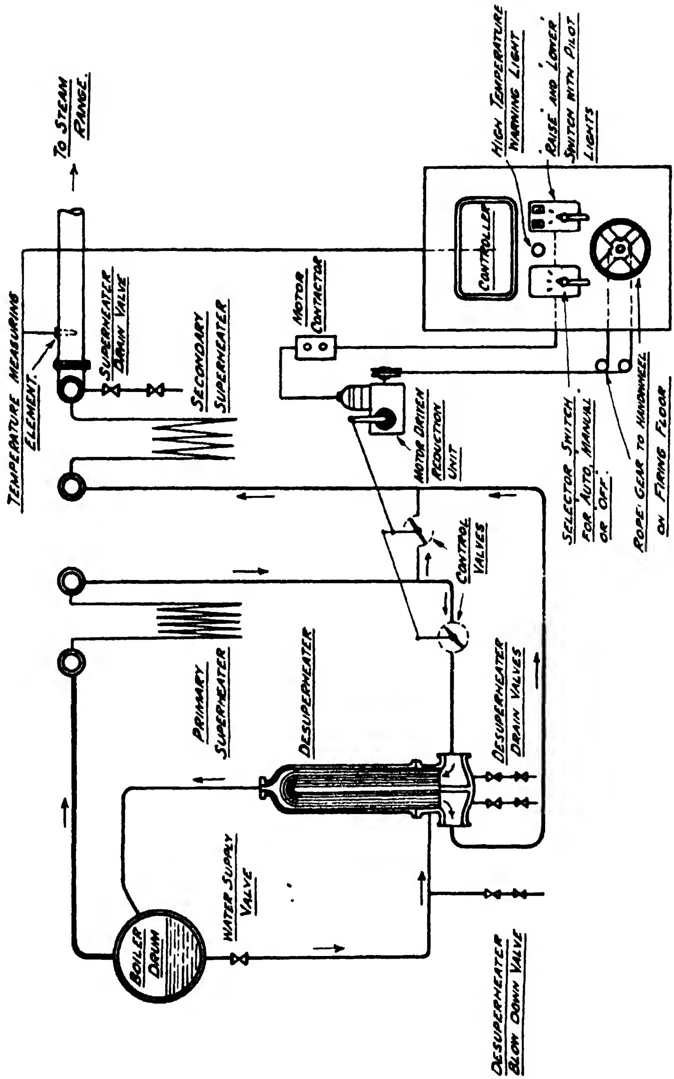


Fig. 139. Diagrammatic Arrangement of Controlled Superheater.

of steam temperature control has been evolved by Messrs. G. Kent in which the regulation of the steam temperature is effected by varying the proportion of the total steam flow which is passed through the

desuperheater. Two butterfly type control valves are included, one of which is in series with the desuperheater and the other in a by-pass. The valves are mechanically connected so that as one valve closes the other opens. The superheater is divided into two sections with the desuperheater and the control valves placed between them, the steam passes through the first section, the desuperheater, and then through the second section. The temperature of the steam in accordance with which the control valves are moved is measured at the outlet of the second section by a mercury in steel thermometer.

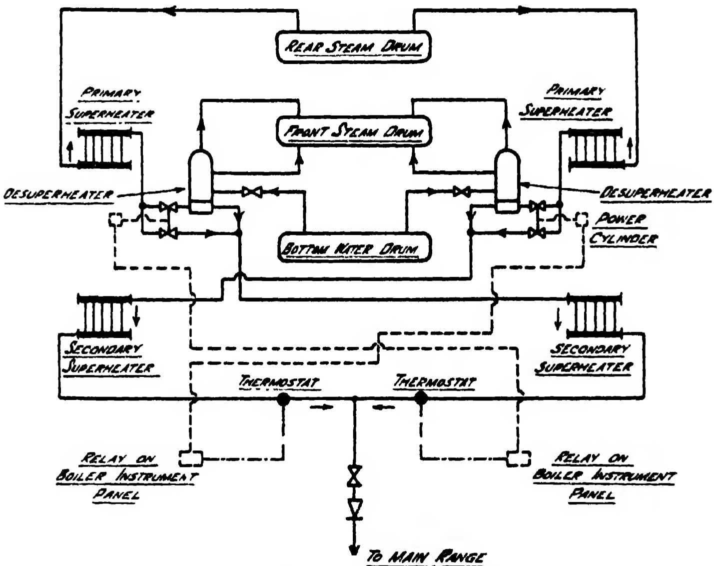


FIG. 140. Connections of Superheaters and Desuperheaters on Boiler Unit.

This consists of a steel bulb connected by a steel capillary tube to a spiral bourdon tube, the whole being filled with mercury under high pressure. The movement of the bourdon tube is magnified by mechanical relay and actuates a gradient analysing mechanism carrying electrical contacts. These contacts energise contactors which control an electric motor in the gear box operating the control. The gradient analysing unit employed is designed to permit correct temperature in the shortest possible time. To assist in operating the plant while the boiler is being put on or taken off the range, and to provide for any emergencies, remote control switches are included.

A three-position switch provides for :—

(1) Full "automatic" plus "remote" plus "hand" control.
(2) "Remote" plus "hand" control.
(3) "Hand" control only.

Coloured lights show the limit of valve travel in either direction. The circuits of the "raise-lower" switch are so arranged that the turning of the switch automatically cuts out for the time being the automatic control and thus ensures that the remote control switch over-rules the automatic control. Coloured pilot lights incorporated in the switch plate show the direction of rotation of the gear box both on "automatic" and "remote" control. To provide complete saftey the gear boxes are designed to admit of hand control by a wire rope drive extended to the firing floor. This is possible by incorporating in the gearing a friction clutch through which the electrical drive is done. The hand control is at all times positively coupled with the output spindle and the friction clutch slips as the hand gear is turned. The hand gear revolves whenever the valves are moved, whether by hand or electrically, and gives an indication of the valve position. An indicator is provided at the control centre showing the valve position at any time. The temperature controller, the remote control switches and the hand gear are arranged on a control panel. Figs. 139 and 140 show diagrammatic arrangements of two schemes. Details relating to one type of superheater are given :—

Working conditions

Fuel	11,500 B.Th.U.'s per lb. as fired.
Feed temperature to economiser	250° F.
CO_2 in gas entering superheater	14·5 per cent.
Gas weight entering superheater :	
Economical load	224,000 lb. per hour.
Maximum load	280,000 lb. per hour.
Pressure drop through desuperheater and superheater	10 lb. at 90,000 lb. per hour. 40 lb. at 188,000 lb. per hour.
Working steam pressure and temperature at superheater outlet	625 lb. p.s.i. and 850° F.
Type	Single-pass with multiple loop elements, intermediate non-contact type desuperheater and automatic steam temperature control.
Location	Behind front bank.
Heating surface	7,500 sq. ft.
Number of tubes	100 (60 primary, 40 secondary).
External diameter of tubes	$1\frac{5}{8}$ in.

Thickness of tubes . . .	7 I.W.G.
Maximum length of tubes . .	120 ft. total length of steam flow per element.
Type of tube joint . . .	Metal to metal ball and cone.
Internal diameter of headers .	10 in.
Thickness of headers . . .	$1\frac{1}{2}$ in.
Total weight of superheater . .	35 tons approximately.
Desuperheater details :	
Cooling surface	250 sq. ft.
Number of tubes . . .	24.
External diameter of tubes .	2 in.
Thickness of tubes . . .	10 I.W.G.
Total weight of desuperheater .	$4\frac{1}{2}$ tons approximately.

ECONOMISERS

An economiser is a form of feed heater, utilising the gases which leave the boiler and transferring part of the available heat to the feed water prior to its entry into the boiler drum. Fundamental laws of heat transfer decree that the gases leaving a boiler must be hotter than the water in the coldest part of the boiler. The actual temperature difference depends on a compromise between the heat wasted in rejecting flue gases at a high temperature, and the extra cost and the additional draught losses involved in providing additional tube surface to absorb the maximum amount of heat. As pressures and temperatures rise, so does the minimum flue gas temperature which can be utilised until, with high pressure boiler plants, the loss would become exceedingly high. If the boiler feed water is already heated to a fairly high temperature by means of steam bled from a turbine the economiser may be unable to use all the waste heat and the inclusion of an air pre-heater may be justified.

Although recovery of heat is the primary duty of the economiser, due regard must be paid to various factors which present difficulties in attaining the desired objective. The gases leaving the boiler are dust-laden and deposition of dust on the heating surface reduces the transmission of heat. The rate of flow of feed water is far from constant whilst the temperature is also variable and, further, steam may be generated. An economiser should be designed and constructed so that the heating surface prevents the accumulation of dust, the tubes expand and contract with freedom under all conditions without putting excessive strain on the joints, and any steam generated in the economiser should escape with the water to the

boiler drum without causing water hammer. Whether an economiser should be included in a boiler is dependent upon the working pressure and the overall thermal efficiency desired. If a boiler of infinite heating surface is installed it could only cool the flue gases to the saturation temperature.

Assuming a boiler pressure of 300 p.s.i. (gauge) then the saturation temperature will be 421° F., and this is the theoretical limit of the temperature of the exit gases. It is found uneconomical to work with temperature differences of less than 100° F., which means that the gases would leave the boiler at 521° F.

Classes. Economisers for power station service are of two classes, namely, steaming and non-steaming. Both have been used and choice will depend largely on the feed-water temperature and the boiler pressure. If the turbines are bled to such an extent that the final feed-water temperature is raised to within a few degrees of the saturation temperature, it is apparent that no further heat can be added in an economiser unless a steaming economiser is used. The function of this economiser is to supply the boiler with a percentage of wet steam along with the feed water and a number of pipe connections are taken from the economiser outlet to the boiler drum. A saving may be effected in both capital cost of the boiler and building with large steaming economisers. The construction and location of both classes of economisers are similar, the chief difference being that only one outlet connection is required on the non-steaming economiser. With a steaming economiser, boiler baffles are eliminated resulting in a reduction in draught loss and fan power. During intermittent feeding with cold feed (banked load conditions), temperature changes occur at the economiser inlet joints which may result in joint failure. Steaming economisers, evaporating 5 to 7½ per cent. of the feedwater by permitting the feed temperature to approach the saturation temperature in the drum, obviate thermal contraction and disturbance to natural circulation. For large boilers the flash-welded continuous-loop type gives freedom from bonded deposits with high-phosphorous coals.

Design and Constructional Details. The heating surface is built up of a number of tubes arranged in groups, the number of tubes in each row, the length of the tubes and the number of groups depending on the performance required, also the layout of boiler plant. The gases flow in vertical paths between the tubes. Various tube arrangements are adopted and the illustrations show some of them. The flow of gases across tubular surfaces has received much attention and plain tubes assembled in straight line arrangement

with the gases flowing between the rows are not ideal, since the gases do not contact the top or bottom surfaces of the tubes. This surface therefore is no more useful than if the tubes were placed touching each other. The tubes may be staggered, but here again there are areas at top and bottom across which the gases do not flow. With these arrangements accumulations are built up on the tails of dust deposited in the " dead " areas which encroach upon the areas traversed by the gases.

The staggering of tubes increases the resistance to gas flow with consequent increase in draught loss and if the gas velocity is reduced to minimise loss then the deposition of dust on the tubes is materially increased. The tubes are arranged with an extended heating surface, either in the form of a circular or ring-gill or alternatively a special " H " section gill. The plain steel tube suffers from the corrosive action of sulphur present in the flue gases. The extended heating surface reduces the tubes required and the number of joints to be maintained. When tubes with extended surface in the form of circular gills are used only those portions of the gills which are in the flow of the gases form effective heat-absorbing surface. Portions of the gills can be omitted, leaving only the side sections, and the inert areas at top and bottom of the tubes can be prevented from accumulating dust. The extension of the portion of the gill remaining in the gas stream is desirable so it is given the form of a straight gill extending more than the full diameter of the tube. Such a gill has been developed by Senior Economisers Ltd. and is known as the Senior " H " type gilled tube (Figs. 141 and 142). When the tubes are assembled in straight vertical rows the gills and plates form straight continuous gas passages of uniform cross-sectional area. Plain surface gills are equally effective and are preferred to corrugated gills. The correct area of gas passages is of prime importance to avoid choking by heavy and hard deposits of dust. It has been suggested that the hydraulic mean radius or cross-sectional area of gas passage divided by the perimeter should not fall below 0·3 (calculated on the basis of inches) if choking is to be obviated. To ensure constant gas velocity the gas passages should be of uniform cross section throughout and free from sudden changes in direction of flow. Any draught loss is then entirely due to friction. Uniform gas passages permit of higher gas speeds without increased loss and less deposition of dust. An economiser should be designed in accordance with the following :—

(1) The gases should come into contact with 100 per cent. of the heating surface irrespective of gas velocity.

(2) Gas passages should be of uniform cross sectional area throughout their length to ensure constant velocity.

(3) Gas passages should have a hydraulic mean radius of at least 0·3, and, as far as possible, be perfectly straight, to avoid gas eddies and pockets for collecting dust deposit.

To prevent formation of steam the outlet temperature of the feed-water should be maintained below saturation temperature corresponding to actual boiler pressure (about 50° F.).

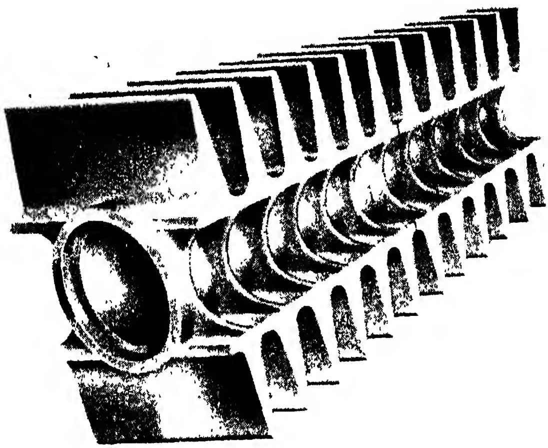


FIG. 141. "H" Type Gilled Tube. (Senior Economisers Ltd.)

A minimum inlet water temperature of about 100° F. is desirable if external corrosion of the tubes is to be prevented due to condensation of steam contained in the flue gases at the cold end of the economiser. It is generally considered advisable to keep the temperature of the feed water to the boiler within about 75 per cent. of the saturation temperature and so prevent "water hammer." The lowest flue gas temperature to prevent a similar occurrence is about 300° F., depending on the sulphur content. The draught loss should be reasonable as the heat transmission factor depends on the velocity, *i.e.*, a higher velocity results in a higher heat transfer factor.

$$Q = k \, . \, A \, . \, MT_D$$

where Q = heat transfer in economiser, B.Th.U. per hour.
k = heat transfer factor, B.Th.U. per ft.^{2} per ° F. per hour.
A = Heating surface area of economiser, ft.^{2}.
MT_D = mean temperature difference, ° F.

The elements are of cold drawn seamless steel tubes on which special "H" section or circular cast iron rings are fitted. These rings, in addition to protecting the steel tubes from the corrosive action of the gases, greatly increase the active heat-absorbing surface. In the "H" section type the gills are on the sides only and the tubes which are connected together are spaced so that the gills

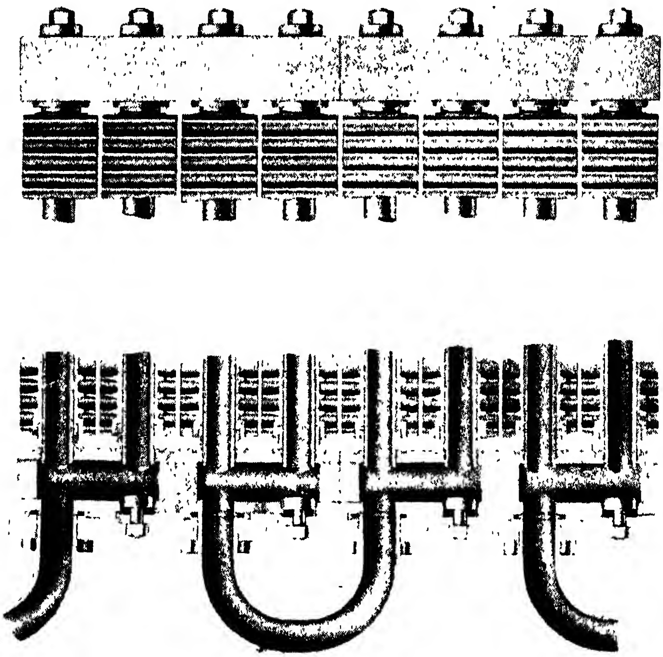


FIG. 142. Part Sectional Elevation showing Headers and Bends of Heenan Twin Tube Economiser.

on each tube are in contact with the gills on the tubes above and below it, thus forming vertical gas passages between the vertical rows of tubes. The gilled pieces are manufactured in lengths of about 6 in. and are machined, a spigot being formed at one end and a socket at the other. The bore is machined slightly smaller than the tube, so that when shrunk on to the tube a good metal-to-metal contact is obtained. The spigot and socket joint between adjacent gilled pieces prevents the gases attacking the steel tube at the joints. Senior Economisers Ltd. assemble their tubes in such a manner that each vertical row has connector boxes at each end, one above the

other, and into each of these boxes are expanded the tube ends of four elements. Those at one end of the economiser are divided in the centre to receive two tube ends in each half, whereas those at the other end are open for their full length, connecting the ends of four tubes. The connector boxes in the bottom and top rows at one end of the economiser are each connected by a steel bend to the inlet and outlet headers respectively. The water flows from the inlet header through a bend into the connector box with a division and then through two tubes to the other end, where the connector box has no division, so that it returns through the two top tubes back to the second half of the divided connector box. At this point connection is made by a steel bend to the first compartment of the divided connector box above, so that water flows through the two bottom rows of this set of tubes, and so up through the economiser. Since there are bends at one end only, the other end is entirely free to expand and contract. The economiser is enclosed in a casing, made up of panels of convenient size consisting of two mild steel plates placed apart, the space between being packed with insulating material. For large units a pulley block is provided to facilitate handling of casing plates. Inspection doors are provided and special doors may be included to relieve pressure inside the economiser casing in the event of flue gas explosions. For very high pressure boilers a special all-welded construction economiser may be used.

Typical details relating to one economiser are given :—

Type-gilled

Heating surface	17,440 sq. ft.
Number of headers . . .	2.
Diameter of headers . . .	$6\frac{1}{2}$ in. externally.
Thickness of headers . . .	$\frac{3}{4}$ in.
Number of tubes	308.
Diameter of headers . . .	2 in. externally.
Thickness of tubes . . .	5 I.W.G.
Length of tubes	20 ft. 2 in.
Total weight of economiser . .	130 tons, with water.

The following details refer to a similar economiser :—

Economiser safety valve . .	875 lb. p.s.i.
Evaporation of boiler . . .	150,000 to 187,500 lb. per hour.
Weight of gases	243,000 to 302,000 lb. per hour.
Temperature of gases entering economiser	735° to 805° F.
Temperature of gases leaving .	387° to 421° F.
Temperature of water entering economiser	250° to 265° F.

Temperature of water leaving	.	381° to 407° F.
Draught loss through economiser	.	1·20 to 1·91 in. W.G.
Water pressure loss	. . .	6·0 to 9·0 lb. p.s.i.
Temperature of saturated steam	.	531° F.

AIR PREHEATERS

As boiler pressures increase it becomes less possible to extract the heat from the flue gases in the economiser because feedwater heating prevents the economiser fulfilling its primary function and the gases have to be cooled to an economical temperature by heating the combustion air.

Air preheaters are necessary to preheat the air required for combustion, the heating medium being the flue gases leaving the economiser. The use of preheated air assists early gasification and ignition of the carbon and promotes high furnace temperature. The final temperature of the air will depend upon the method of firing and classes of coal. For pulverised fuel firing air temperatures of 450° to 650° F. are possible, whereas in stoker-fired boilers the maximum permissible temperature would be about 400° F., though in practice temperatures of 250° to 300° F. are more usual for chain grate stokers. Preheated air is a necessity with pulverised fuel firing, a decided advantage to stoker-firing and is the only simple means available for the reduction of the final flue-gas temperature. The value of the preheater is especially evident where low-grade fuels are used. Air heater surface is much cheaper than equivalent economiser surface, but the extent to which the latter can be replaced by the former depends upon the permissible temperature at which the gases enter the air heater.

Types. There are four types of heaters :—

(1) Tubular.
(2) Plate.
(3) Rotary or regenerative (with serrated, plain or needle elements).
(4) Tubular—needle or gilled.

In the tubular heater the air is passed across the tubes and the flue gases pass through the tubes or *vice versâ*. Cleaning is easier when the gases pass through the tubes. The rate of heat transfer is low and the space occupied is generally prohibitive. This type of heater may be used with high temperatures. Tubular heaters with cast-iron tubes at the low temperature end to minimise corrosion may be used. Trouble is experienced in cleaning long tubes and there is an added disadvantage in that considerable space is necessary for withdrawal of the tubes. To overcome this difficulty on large units

they are frequently arranged in two sections or groups. Aluminium alloy tubes have also been used. The plate type was very popular until the rotary heater was developed. The gilled or needle type of heater is also in use. The tubes are of cast iron, the gases passing through plain tubes and the air over the pointed gill surfaces.

Design and Constructional Details. Whatever type of heater be adopted it should have a high thermal efficiency, be reliable, require little maintenance, occupy small space, be accessible, and be reasonable in first cost. Heaters are simple pieces of equipment and providing they are operated in accordance with boiler conditions obtaining, and maintained in good order, very little trouble will be experienced. Leakage between the gas and air sides should be a minimum.

High dew-point temperatures are responsible for repeated heavy deposits with consequent choking and corrosion. Pulverised fuel boilers are not so prone to this trouble the larger percentage of ash dust in the flue gases maintaining lower dew-point temperatures and also combustion is more complete. Fly-ash from these boilers is usually lower in sulphur content than that from stokers. It is possible that the higher metal temperatures (boiler and superheater tubes, etc.) over which the flue gases pass on their way to the chimney may be responsible for these higher dewpoints now obtaining.

It has been suggested that if the gases flow into the regenerative heater from the top, choking and corrosion are reduced, but in practice no difference is found from that which is obtained with the gases entering from below. An advantage is that with the cold end at the top any deposits removed by soot blowing will be immediately carried away from the heater. With the cold end at the bottom the heater gasses would be subject to the passage of the displaced deposits. With the gas flowing downward through the heater the momentum of the dust particles may prevent sticking to the plates whereas in moving upwards there is a greater tendency for them to adhere to the plates.

The plate type consists essentially of an assembly of hollow leaves electrically welded to ensure gas tightness the contra-flow principle being used. The gases flow along the outsides of the leaves and the air to be heated is forced through the leaves. Trouble was experienced with this type due to choking and corrosion of the gas paths, this being due to heater operating under dew-point condition of the gases. Choking and corrosion took place at the gas outlets but this was overcome by making the gas passages not less

than ⅜ in. wide whilst the plates were made of copper bearing steel and recirculation of hot air was introduced.

For dew-point considerations it is desirable that the temperature of the inlet air to the preheater should be not less than 130° F., this being achieved by recirculating air from the preheater discharge to the forced draught fan inlet.

A small heater may be placed in series with the main heater so that if replacement of the cold end of the heater is necessary the

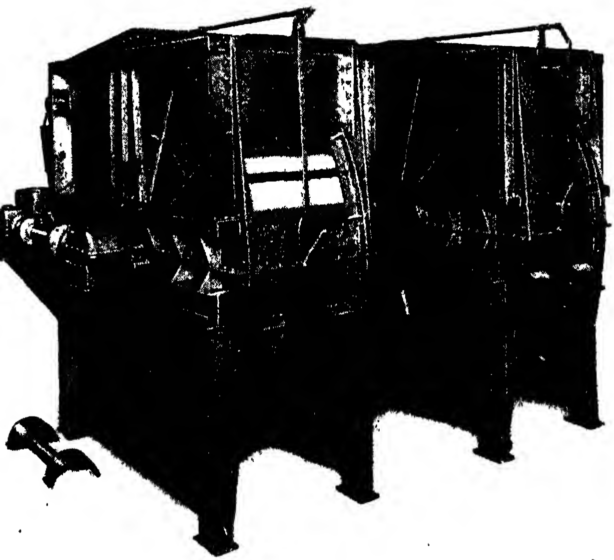


FIG. 143. Two Horizontal Shaft Rotary Air Heaters (J. Howden & Co. Ltd.)

major portion is not disturbed (Fig. 119). The steaming economiser is followed by a secondary preheater, then a first step economiser and a primary preheater. Calculations show that to reduce the flue gas temperature to the low figures specified requires such a combination. This type of heater has no moving parts, is very simple in construction and can be placed either below or adjacent to the economiser. For large boilers the heater may be divided into two or more sections, dampers and by-pass ducting being provided.

The rotary or regenerative type is popular for large boiler units and is known as the Howden-Ljungstrom heater. It is built up of a slowly revolving drum containing thin corrugated sheet metal

members offering surfaces to be heated by the flue gas. The heated corrugated plates are revolved for half a turn and are then exposed to a stream of cold air, the air absorbing the heat retained by the elements. By this process the heat in the flue gases is partly recovered and returned to the furnace. It acts as a continuous regenerator and heat transfer takes place in pure contra-flow. The heating elements are made of mild steel sheets kept at a fixed

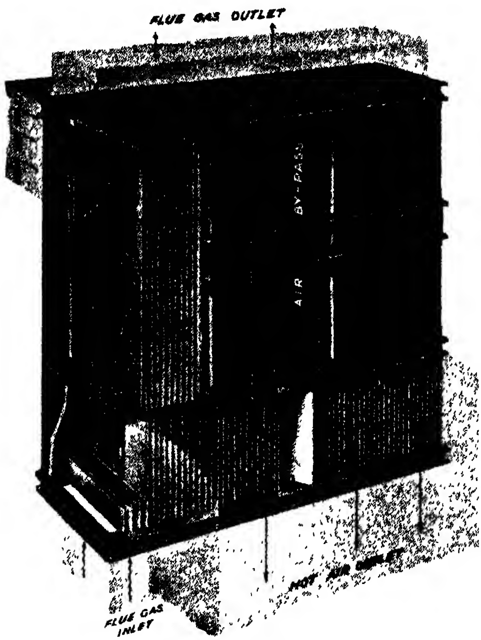


FIG. 144. "Usco" Patent Uniform Flow Air Heater—"S" Type. (International Combustion Ltd.)

distance from each other. They are partly or entirely corrugated or undulated to give a turbulent flow of the gases and air and can be withdrawn from the rotor. The thickness of the elements is about 22 S.W.G., and it has been suggested that a minimum spacing of ½ in. should be allowed to ensure long uninterrupted working periods. The sections of elements are of such size and weight that they can be handled without the aid of lifting gear, access doors provided in the casing permit of this being done. Arrangements are incorporated for adjusting clearances and the casing is lagged to suit temperature conditions. The rotor is divided into a number of sections (usually

twelve) by means of radial division plates, each section being filled with elements. Radial sealing strips are attached to these division plates to reduce leakage. The driving rack is welded to the rotor shell and the rotor revolves at a speed of about 4 r.p.m. By-passes are included to adjust air temperature to suit combustion conditions, or for use when starting from cold or running at light loads when there may be some risk of dew deposits, choking and corrosion. Vertical and horizontal preheaters are made and two heaters are used on large boilers. The advantages of the rotary heater are: compactness, occupies small space, accessibility and reduced weight. Against

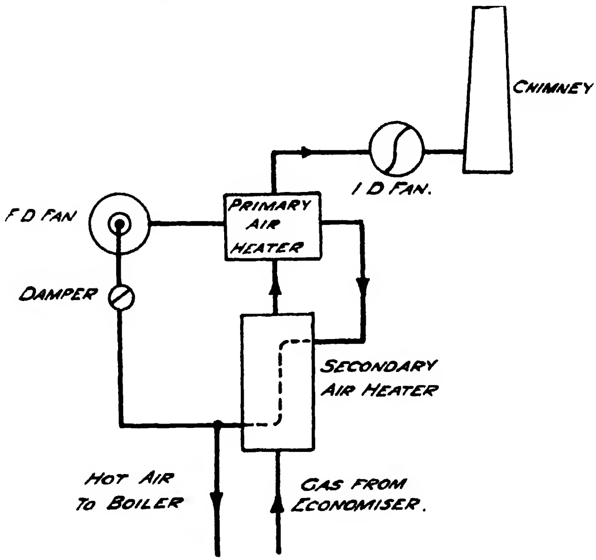


FIG. 145. Air Heater with Primary and Secondary Sections.

these it has moving parts, leakage cannot be entirely eliminated and auxiliary power is required. Figs. 145 to 147 show some usual layouts.

With regenerative heaters the usual method of raising the minimum heating surface element temperature at the cold end to avoid or reduce deposit or corrosion is by air by-passing. On the recuperative heater, with its wide gas and air inlet openings, it is usual practice for air recirculation to be used to bring the air inlet temperature slightly above the anticipated dewpoint of the flue gases to afford protection against local cold spots in the heating surface at the air inlet end should air at high velocity be passing at one side of the tubes or plates, and gas at low velocity at the other. Where this condition occurs, locally, in any recuperative heater, the

plate temperature tends towards the air temperature and may fall almost to that figure, so that raising the air inlet temperature to the expected gas dewpoint by means of air recirculation gives

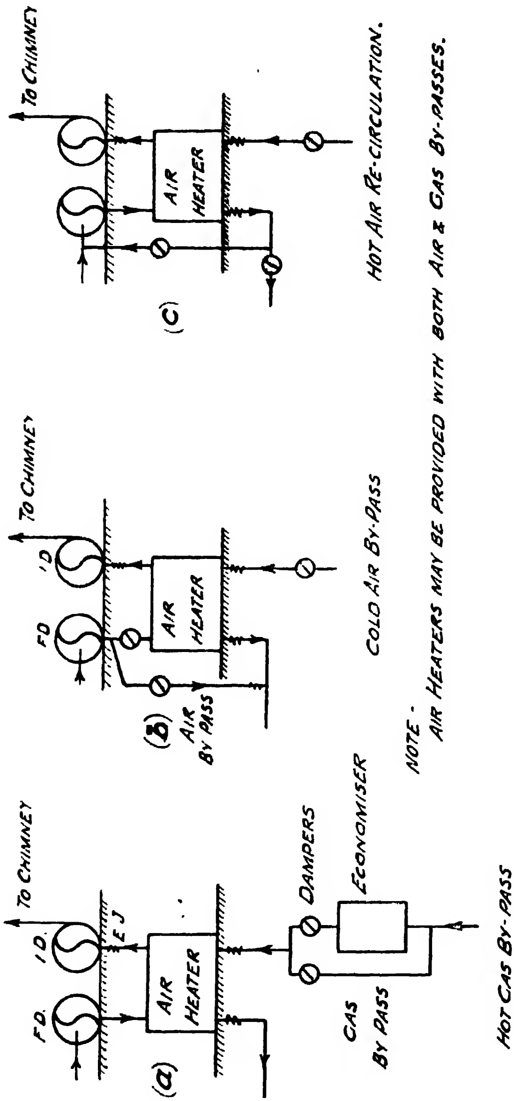


Fig. 146. Methods of Preventing Corrosion and Deposits on Air Heaters.

protection against the worst possible condition of distribution across the preheater air inlet.

With the regenerative air preheater, all the element plates in

turn rotate through the streams of gas and air and are all subjected to substantially similar conditions, so that the minimum element temperature is uniform over all sections of the heating surface ; it can be estimated with reasonable accuracy, and during design be kept at a suitable level. Air recirculation can then be dispensed with, and air by-passing, which is simpler, more flexible, and usually more effective method of control can be used.

For flue gases with normal dewpoint, there is little difference economically in the two methods of control. Air recirculation has to be paid for by increased F.D. fan power owing to the larger air volume and higher air side resistance of the preheater, and air by-passing by increased flue gas loss following the raised gas outlet temperature. With worsening flue gas conditions requiring greater increases in permissible plate temperature, air by-passing becomes more favourable than air recirculation. This is partly for the reason that increased air flow rate through the preheater with air recirculation increases the air side transfer coefficient, which lowers the element temperature level, counteracting to some extent the increase in minimum plate temperature expected from the raised air inlet temperature. With air by-passes the converse is true. Reduced air side flow rate reduces the air side transfer coefficient, raising the plate temperature level, and thus augmenting the rise in element temperature resulting from the increased cool end flue gas temperature (see *Steam Engineer*, March and April, 1952).

Typical details relating to air heaters are given :—

Type	Rotary	Plate
Number per boiler	2	1
Heating surface	6,500 sq. ft.	18,900 sq. ft.
Draught loss : Air N.E.R.	1·50 in. W.G.	1·55 in. W.G.
,, ,, ,, M.C.R.	2·20 ,,	2·20 ,,
,, ,, Gas N.E.R.	1·60 ,,	1·25 ,,
,, ,, ,, M.C.R.	2·20 ,,	2·00 ,,
Material of elements	Mild steel	Mild steel
Thickness of elements	22 S.W.G.	12 S.W.G.
Thickness of casing.	$\frac{1}{4}$ in.	$\frac{3}{16}$ in.
Total weight	13 tons	49 tons

Chain Grate Stoker. Two rotary heaters. Operating conditions at normal load are :—

Gas in . .	460° F.	Air in . .	80° F.
Gas out .	240° F.	Air out . .	344° F.

Boiler capacity 150,000 lb. per hour.

Retort Stoker. Two rotary heaters. Operating conditions at normal oad are :—

Gas in . .	512° F.	Air in . .	60° F.
Gas out .	240° F.	Air out . .	400° F.

Boiler capacity 260,000 lb. per hour.

Pulverised Fuel. Two rotary heaters. Operating conditions at normal load are :—

Gas in . .	512° F.	Air in . .	95° F.
Gas out .	270° F.	Air out . .	410° F.

Boiler capacity 250,000 lb. per hour.

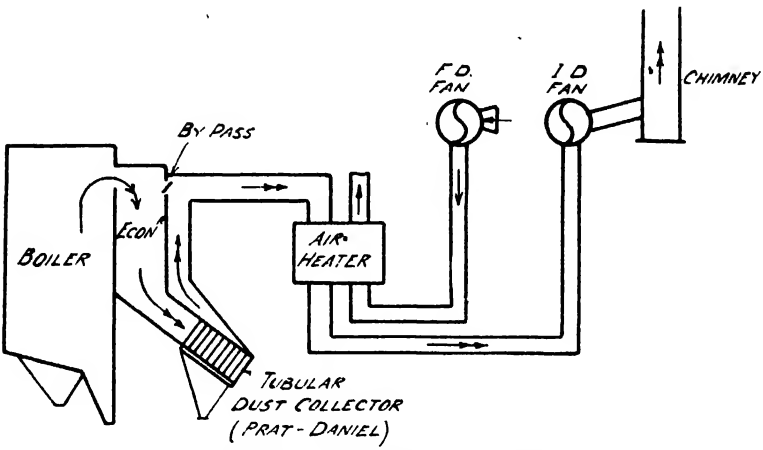


Fig. 147. Tubular Dust Collector.

Chain Grate Stoker. Boiler capacity 187,500 lb. per hour M.C.R.

Type of heater	Rotary.
Heating surface	7,800 sq. ft. each.
Gas quantity entering 2 preheaters .	246,000—306,000 lb. per hour.
Gas quantity leaving 2 preheaters .	268,000—334,000 lb. per hour.
Air quantity entering 2 preheaters .	231,000—289,000 lb. per hour.
Air quantity leaving 2 preheaters .	209,000—261,000 lb. per hour.
Gas temperature entering preheaters .	385°—420° F.
Gas temperature leaving preheaters .	250°—274° F.
Air temperature entering preheaters .	90° F.
Air temperature leaving preheaters .	249°—261° F.

Draught loss through preheaters :—

Flue gas side . . .	1·1—1·6 in. W.G.
Air side	0·9—1·4 in. W.G.

Figs. 148 and 149 show the temperatures of flue gases through the different sections of heat-transferring units.

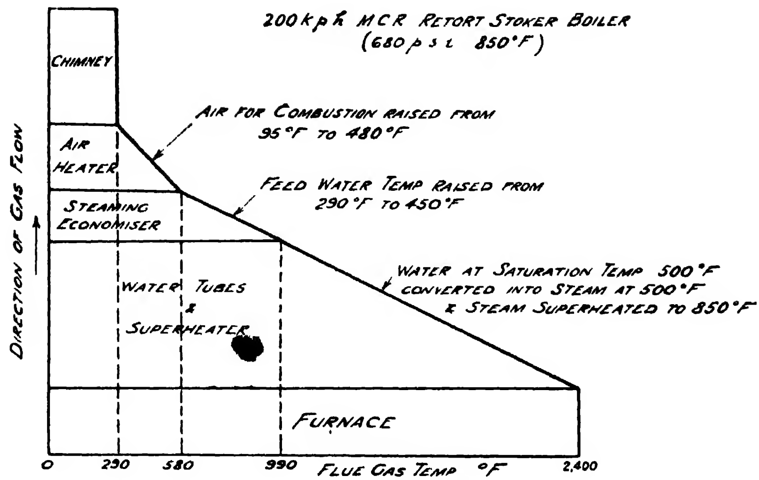


FIG. 148. Temperatures of Flue Gases as they Flow through the Heat-transferring Units.

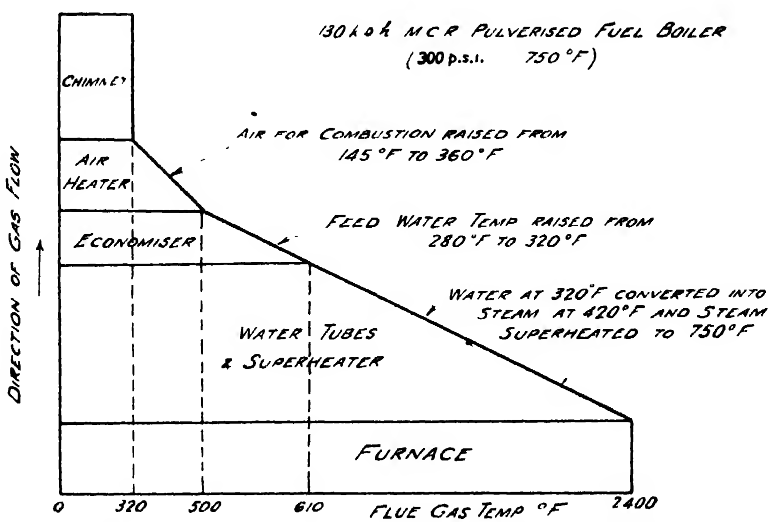


FIG. 149. Temperatures of Flue Gases as they Flow through the Heat-transferring Units.

MECHANICAL DRAUGHT PLANT

The mechanical draught plants associated with large boiler units are important sections of the auxiliary equipment and much attention has been given to their design, construction and layout. Large boiler units have high rates of heat release and since the speed of combustion is almost entirely dependent on the relative velocity between the fuel, air and gases, the combustion process is controlled by the method in which the air is introduced and by the speed at which the mixing takes place. High air and gas velocities throughout the various positions of the boiler are desirable.

The velocities through the different passes vary for each boiler and the following relate to an 80 k.p.h. boiler :—

Flue Gas Temp. °F.	Velocity ft./min.	
320	1,880	10 per cent. CO_2; velocity measured at base of chimney (28 ft.^{2}).
340	1,940	
360	1,980	
320	1,580	Ditto 12 per cent. CO_2.
340	1,630	
360	1,670	

A gas velocity of between 20 to 35 ft. per sec. appears to be usual.

The following figures refer to a 200,000 lb./hr. boiler :—

Boiler tubes	1,000	ft./min. gas velocity.
Superheater tubes	1,500	,, ,,
Economiser tubes	2,500	,, ,,

The draught on the boiler is dependent upon the speeds of the forced and induced draught fans, which can be hand-regulated to suit any quality of coal or rate of combustion. The resistance to be overcome by the fans has increased together with the boiler capacity and the power consumption of the fans is such that fans having a high efficiency over the range of output are essential. To produce a given static head a certain peripheral speed is required which may be attained by using a small fan to run at a high speed or a large fan to run at a low speed. High speeds result in the use of smaller fans and motors but consideration should be given to supporting structure and bearing design. Fig. 150 indicates a typical boiler draught system.

Pressure Firing. In this system of firing the induced draught fans are omitted but the forced draught fans are of considerably greater power, so that the combustion chamber operates under an

appreciable air pressure instead of atmospheric, or a slight vacuum. The advantage lies in the elimination of fans handling hot and dirty gases and the simplification of ducting. The overall fan power is reduced since the forced draught fans do all the work and handle cool air at a high specific volume. Problems arise in connection with inspection doors, ash removal and other openings.

In one American station a 1,340 k.p.h. pulverised fuel boiler has been designed for pressurised firing. This was chosen to secure a tight casing with the attendant freedom from excess air infiltration which a boiler of this type must have if it is to operate satisfactorily indoors. By eliminating I.D. fans it is possible to offset the higher cost of the boiler casing and the higher cost involved in installing this casing. Each boiler has two F.D. fans each delivering 300,000 ft. of 80° F. air with a discharge pressure of 42 in. W.G.

Classes of Fans. Fans for draught plant services are :—

(1) Forced draught.
(2) Induced draught.
(3) Secondary air.
(4) Primary air.
(5) Exhauster.

The terms " Forced " and " Induced " as applied to fans for draught plants designate the relation which they bear to the combustion chamber or fuel on the grate. Forced draught fans draw in air from the boiler house, discharge it through the air heaters to the wind box under the stoker or to the burners and coal drying system in a pulverised fuel boiler. Induced draught fans create a suction and in so doing draw the gases through the boiler passes, economiser, air heaters and gas cleaning plant and on to the chimney. The regulation of both forced and induced draught fans is balanced so that the static depression in the combustion chamber is kept at a minimum to reduce the infiltration of cold air. A condition of " balanced draught " exists when the pressure immediately above the fuel bed on the grate equals atmospheric pressure, this being obtained by regulating the fan speeds so that the forced draught fans supply a pressure just sufficient to force the air through the fuel bed while the induced draught fan creates a suction to enable the gases to be drawn through the heat-transferring units. The volatile content of the fuel is given off some distance from the main or primary air supply and unless there is turbulence and a sufficient supply of air in the combustion chamber, combustion will be incomplete. The escape of unburned gases results in loss of efficiency and smoke emission and secondary air may be necessary.

To produce turbulence the secondary air fans discharge the air at high velocities to obtain a sufficient depth of penetration into the gas stream. Preheating the secondary air to a high temperature facilitates combustion. The secondary air is taken from the main air ducts on the outlet sides of the air heaters and discharged by the fans into nozzles provided in the front and rear combustion chamber walls. Primary air and exhauster fans are used for pulverised fuel boilers.

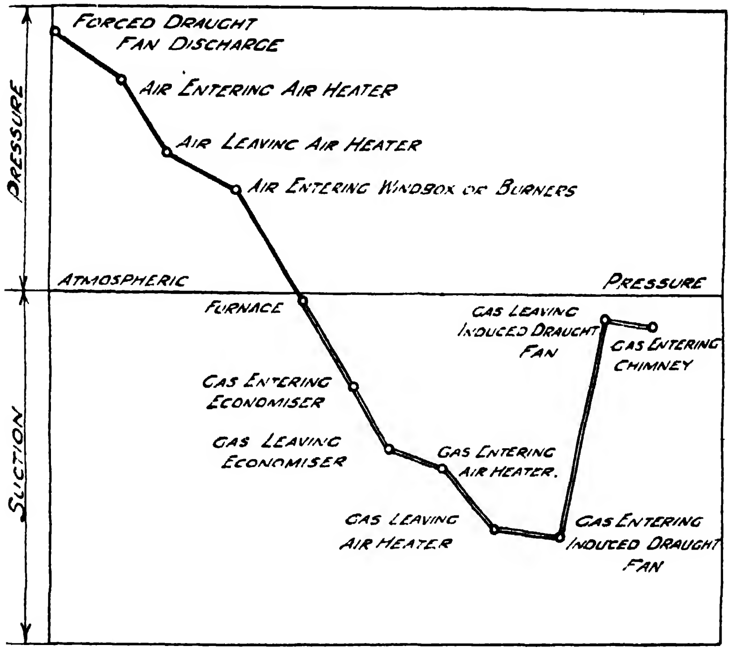


FIG. 150. Draught System.

Design and Constructional Details. Fans are constructed in three distinct types, namely, the backward curve blade, radial blade and the forward curve blade. The classification of fan types applies to the direction of the blade surface at the delivery edge and will be understood on referring to Fig. 151. The inner edge or "heel," where curved, should always be inclined forward to reduce the entering shock. The shape and form of the fan characteristics depend chiefly on the design of the fan blades. The choice of type will depend primarily on whether air, flue gases, grit or pulverised fuel has to be handled. Forced draught fans handle cold clean air

and the design need only be such as to provide for high speed, high efficiency and a maximum of reserve pressure for a given air quantity. The backward curve blade meets these requirements best, as with this type the pressure-volume characteristic is steep rising and the static efficiency is very high. This type of fan also has the advantage that the power consumption reaches a maximum which

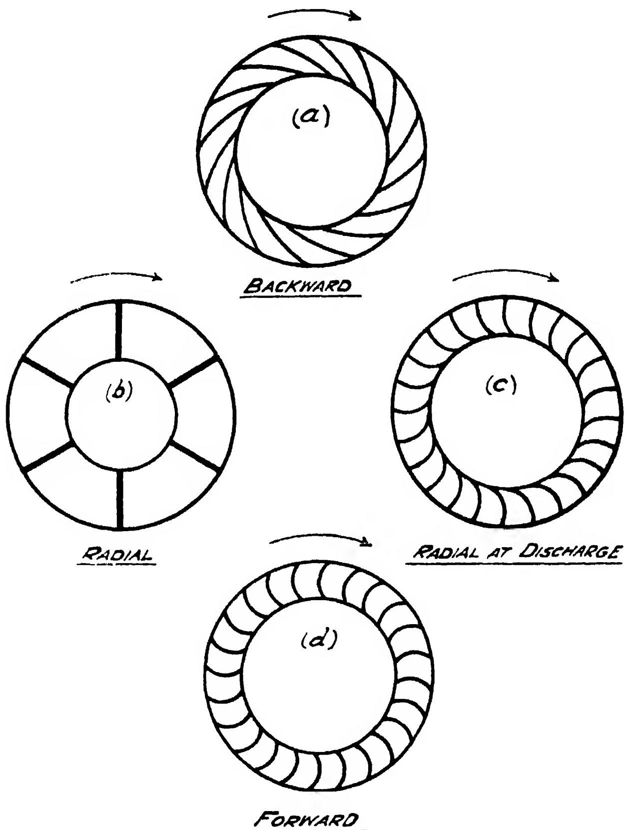


FIG. 151. Types of Fan Blades.

cannot be exceeded (Fig. 152). This facilitates the selection of the driving unit since no damage can be done to the motor, with the fan discharging its maximum volume, if the actual system resistance turns out to be lower than that for which it was designed. The backward curved blade requires a higher peripheral speed for the same head than other types and is suited for parallel operation. Induced draught fans handle gases containing soot and dust which

estimated with care, due allowance being made for dirty conditions of boiler plant and range of firing. An additional 10 to 30 per cent. should be added to the capacity and static head of the fan.

It is usual to install two forced and two induced draught fans, each fan being designed to handle 60 per cent. of the total volume of air or gas. If secondary air fans are included they may take up to 20 per cent. of the total air required for combustion from the main hot air ducts and boost the pressure sufficiently to give the requisite draught at the nozzles in the combustion chamber walls.

The bearings of the induced draught and secondary air fans are water cooled. Self-aligning bearings with spherical seating to minimise wear on the sleeves are used for large fans, but small fans have ball and roller type bearings. The fan casings are split either in the horizontal or vertical planes, or both, depending upon the size of the fan, to give access to the impeller. This also permits the removal of the impeller and shaft without disturbing the alignment of the bearings. Leakage between the wheel and casing at the inlet is reduced to a minimum, and that between the shaft and the casing is eliminated by a sealing arrangement. Inspection doors are also included. Some of the troubles met in fan installations are (1) deposits on blades ; (2) pitting and erosion of blades ; (3) knife edging of blades due to sandblasting by grit particles ; (4) distortion of blades ; (5) fan casing distortion ; (6) driving shaft too small in diameter ; and (7) inadequate bearing surface and cooling for the temperatures obtaining. The following formulæ are useful in connection with fans :—

$$\begin{array}{ll} \text{Quantity or volume} & \propto \text{speed.} \\ \text{Pressure or static head} & \propto \text{speed}^2. \\ \text{Output or B.H.P.} & \propto \text{speed}^3. \end{array}$$

$$\text{B.H.P.} = \frac{Q \,.\, H \,.\, 5{\cdot}2 \,.\, 100}{33{,}000 \,.\, Fe.}$$

where

Q = volume of air discharged in ft.^{3} per minute.
H = pressure at discharge in. W.G.
Fe = fan efficiency per cent.

Air entering forced draught fan at 100° F. (see also Chapter II, Boiler House) has an absolute temperature of 560° F. and gas leaving air heater at 300° F. has an absolute temperature of 760° F.

Volume of gas leaving heater is $\frac{760}{560}$ or 1·36 times that of the air

entering forced draught fan. As the volume of a gas increases the weight per cu. ft. decreases, and the weight of the same volume of gas is inversely proportional to its absolute temperature.

The speed of the same fan necessary to handle the same weight of gas is directly proportional to the absolute temperature of the

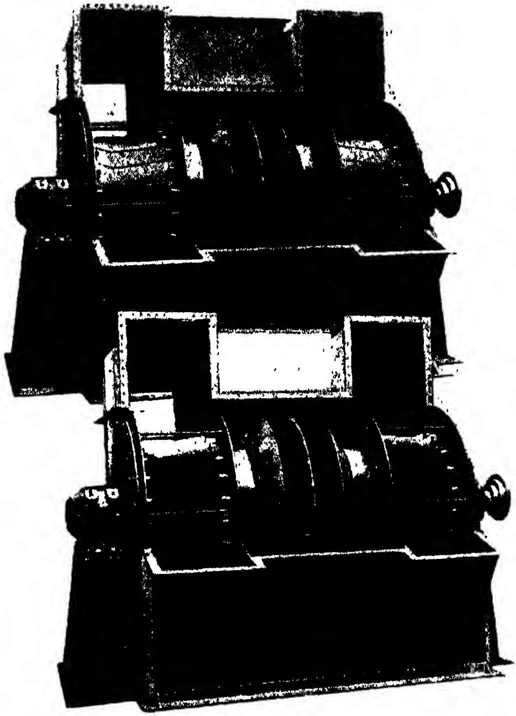


FIG. 153. I.D. Fan with Vane Control. Vanes shown in closed and open positions. (J. Howden & Co. Ltd.)

gas. If the absolute temperature of a given weight of gas be doubled, the volume is doubled and the fan must run at twice the speed. Fig. 153 shows induced draught fan fitted with vane control.

Draught Control. With the difference in the performances required of the fans on the air and gas sides, it is desirable that with any system means must be provided for the individual control of each fan. When two forced and two induced draught fans are

necessary for each boiler then it is essential that accurate control be provided to ensure good parallel operation. Electrical drive is now almost universally adopted. There are three chief methods of obtaining draught control :—

(1) Fans driven by constant speed motors, control being obtained by dampers.

(2) Fans driven by variable speed motors or by hydraulic couplings if constant speed motors be used.

(3) Fans driven by constant or variable speed motors, the fans being provided with inlet vane control.

Damper Control. This is a simple, cheap and reliable method of draught control since the dampers are robust and a squirrel cage " direct on line " motor can be used. With a fan driven at constant speed, the suction or discharge pressure developed is a definite function of the volume given by the constant speed characteristics of the fan. The pressure required for volumes smaller than the design duty will, in most cases, be less than the design pressure. The difference between pressure corresponding to the constant speed characteristic and that required for the smaller volume has therefore to be used up by additional reistance in the system, such as an adjustable damper. There is thus an unavoidable loss of energy at low outputs which makes this method inefficient.

Variable Speed Fan Drives. In control by speed variation the fans are driven by variable speed motor although steam turbines can be used. The motor may be of the slip-ring a.c., d.c. shunt (usually compounded) or a.c. commutator type. Much will depend upon the station auxiliary supply system particularly regarding the use of d.c. auxiliaries. Commutator motors have proved quite satisfactory for fan drives even in pulverised fuel installations. These motors, both a.c. and d.c., have a good efficiency over a wide range of speed and load, but are expensive. Variable speed may also be obtained by using a constant speed motor and hydraulic coupling. Hydraulic couplings require more space and are additional plant to be maintained. Many combinations are possible to obtain the desired degree of speed regulation.

The fan pressure varies as the square of the speed, and the volume delivered is in direct proportion to the speed, the fan pressure-volume characteristic becoming flat as the speed is reduced. There is tendency for unstable operation at reduced loads when two fans discharge into a common system. The power required to drive a fan is proportional to the cube of the volume, so that speed variation is an economical method of controlling fan output, from the point

of view of driving power. The fan horse-power should not be confused with the energy input to the driving unit. If the efficiency of the motor at reduced speed and load is considered it will be found that the energy input to the unit does not fall off in proportion to the fan B.H.P. Speed variation has the opposite effect on the pressure-volume characteristic of a fan to that of vane control.

Vane Control. This consists of a set of vanes at the fan inlet, the fan being driven by a single- or two-speed squirrel-cage motor. The operation of the vanes is by means of a small motor-driven controller and the output is controlled by changing the constant speed characteristics of the fan so that it passes through the desired working point. This is attained by creating and varying at the fan inlet, a swirl in the direction of rotation and concentric with the fan impeller. A set of pivoted vanes at the fan inlet enables this to be done. Closing the vanes reduces the volume handled, and increases the intensity of swirl. The increased swirl reduces the total head developed and thereby reduces the power absorbed. For each position of the vanes, new constant speed characteristics are obtained. As the vanes are closed, the pressure-volume curve becomes more steep and the conditions for stable operation are improved, a change in the system resistance having little influence on the output of the fan. This is desirable when fans work in parallel on a common system and share the load equally or to give correct distribution in the boiler. Whilst good results are obtained with a single-speed motor, vane control shows even better results with a two-speed squirrel-cage motor. With two-speed motors it is found that the normal load and a little more may be carried on the lower speed whilst at the higher speed the fan has ample capacity to deal with overloads and abnormal conditions. Two running speeds have advantages in that the efficiency of both the fan and motor at normal load are high and for normal operation the unit runs at a lower speed. The vane mechanism can be arranged for fans with either scroll or open type inlets. Fans with the scroll type of inlet, have fixed vanes in the scroll to distribute the gases uniformly into the fan impeller. Open inlet fans have vanes arranged radially in an extension to the inlet. Power input curves for various drives are given in Fig. 154.

Air and Gas Ducts. The arrangement of the air and gas ducting and dampers will be governed by the layout of the fans, air heaters economisers and chimneys. Some idea of the cross sections of the ducts for a boiler of 190,000 lb. per hour steaming capacity will be gathered from the following :—

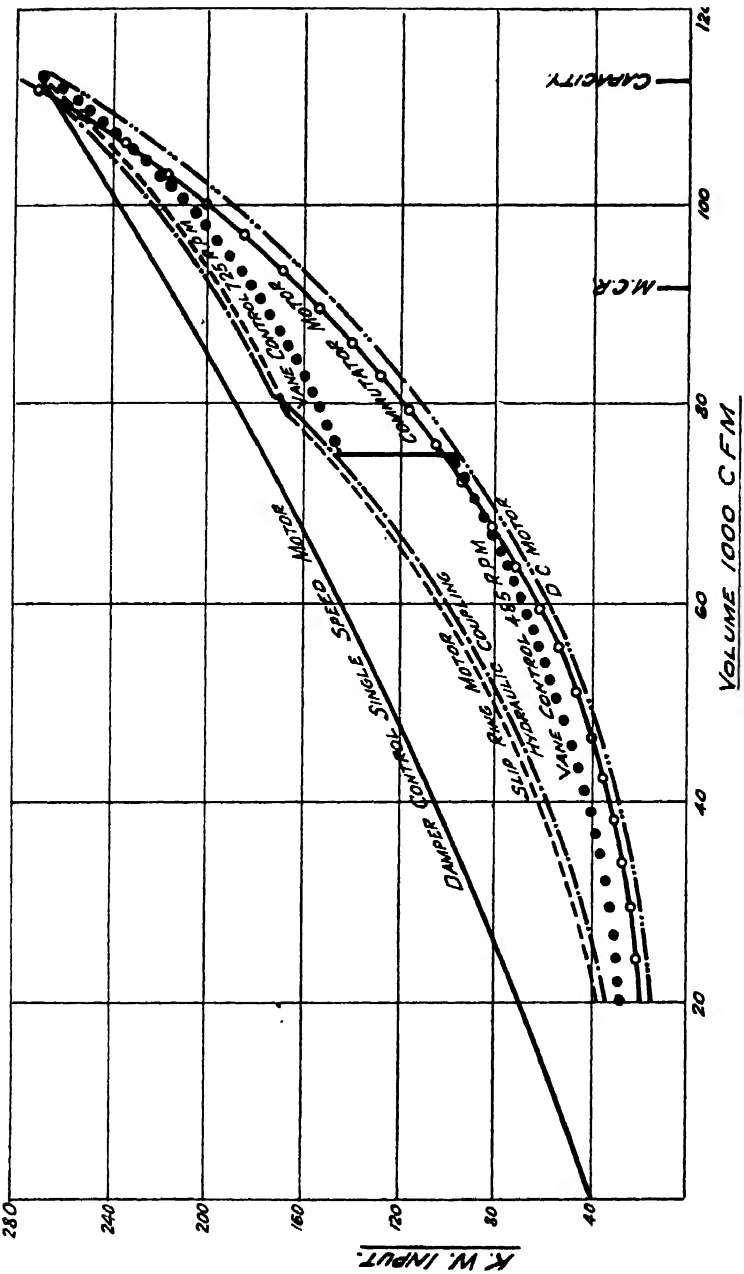


FIG. 154. Power Input Curves for Various Types of Drives.

Air ducts .	7 ft. 0 in. × 3 ft. 9 in.	inlets to stoker wind box.
	6 ft. 0 in. × 3 ft. 6 in.	inlet to fan. (2 fans per boiler.)
Gas ducts .	11 ft. 0 in. × 4 ft. 0 in.	discharge to chimney.
	8 ft. 6 in. × 3 ft. 6 in.	economiser discharge.
	9 ft. 0 in. × 3 ft. 11 in.	gas inlet to air heater. (2 fans per boiler.)

Sharp bends should be avoided and it may be necessary to provide guide vanes to reduce pressure losses and keep the motor power

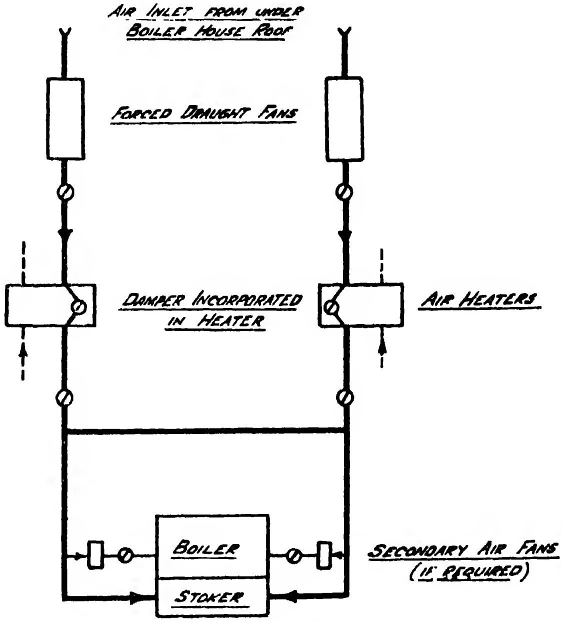


FIG. 155. Air Circuit—Stoker-fired Boiler.

within reasonable limits. The forced draught fan inlet may be taken from the top of the boiler house, thus increasing the overall efficiency slightly, cooling and ventilating the building, and obtaining the most even temperature possible in the air supply both in Winter and Summer.

The ducts for both air and gas are of steel plates $\frac{3}{16}$ in. thick stiffened, supported and made perfectly airtight. Gas and hot air ducts are of the double plate type, the inner plate being $\frac{3}{16}$ in. thick and the outer $\frac{1}{16}$ in. thick. The space between the inner and outer plates is filled with heat insulating material such as glass silk,

asbestos and silica. Some sections of gas and hot-air ducts may be insulated internally and externally. The internal lining serves to resist corrosion and erosion and it is not subject to injury when gaining access to other items of plant. Block slag-wool insulation has been used on flat surfaces. Plastic insulating

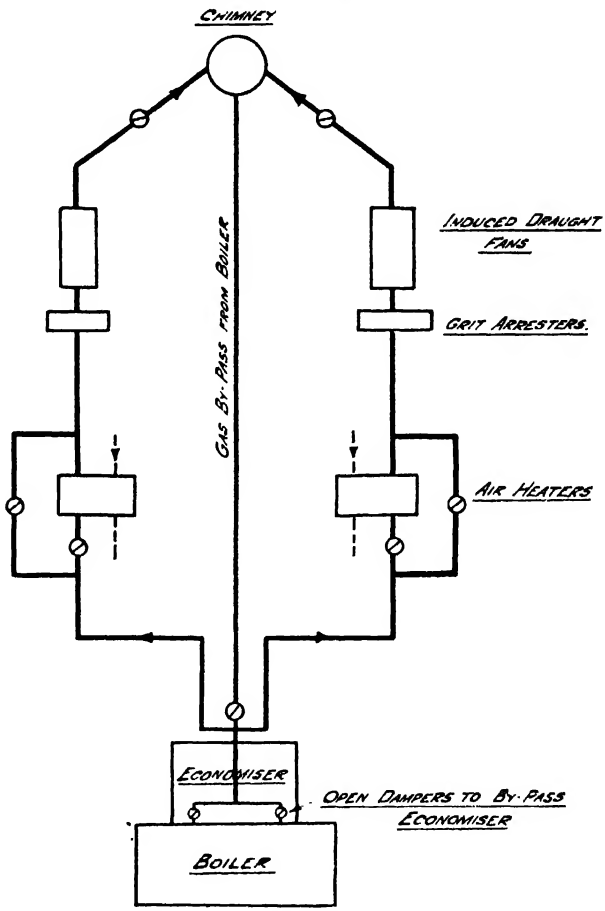


FIG. 156. Gas Circuit—Stoker-fired Boiler.

composition reinforced with wire netting secured to the casing and finished off with hard setting composition has also been used. Glass silk insulation of 2 in. thickness (depending on position) used on stoker and pulverised fuel installations gives good results. Expansion and contraction should be allowed for by the inclusion of bellows pieces in the ducting. Sliding joints have been used and

appear to be satisfactory. Panelling of the lagging on duct-work prevents cracking of the hard setting cement caused by temperature and vibration. Casing plates of handable sizes are preferable and access doors should be included to facilitate cleaning. To prevent accidents, safety platforms are necessary at all dangerous changes in levels of the ducts. Platforms of $\frac{5}{8}$ in. diameter rods at 9 in. centres are suitable. Fan inlets should have an expanded metal screen to prevent the ingress

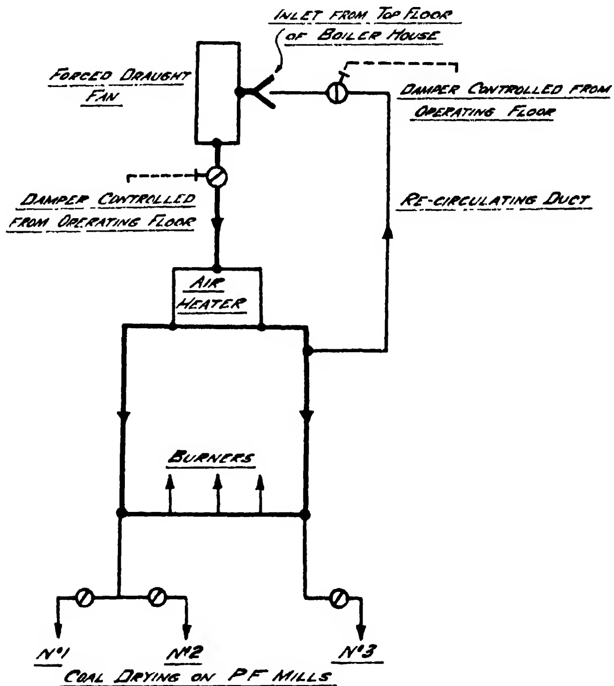


Fig. 157. Air Circuit—Pulverised Fuel Boiler.

of materials and minimise danger to attendants. It is necessary to include pyrometer and draught points of measurement and an advantage to include a check point at each pyrometer connection. The check point connections should have a screwed cap attached to a chain. Typical diagrammatic layouts of gas and air circuits for both stoker and pulverised fuel boilers are shown in Figs. 155 to 158.

Layout of Draught Plant. The layout of this plant depends primarily in the arrangement of boiler, economiser, air heater and

chimney. Various layouts are to be found in practice, some of which are :—

All fans at basement level.
All fans at operating floor level.
All fans at roof level or at an upper floor level.
F.D. fans at roof level and I.D. fans at operating floor level.
I.D. fans at roof level and F.D. fans at basement level.

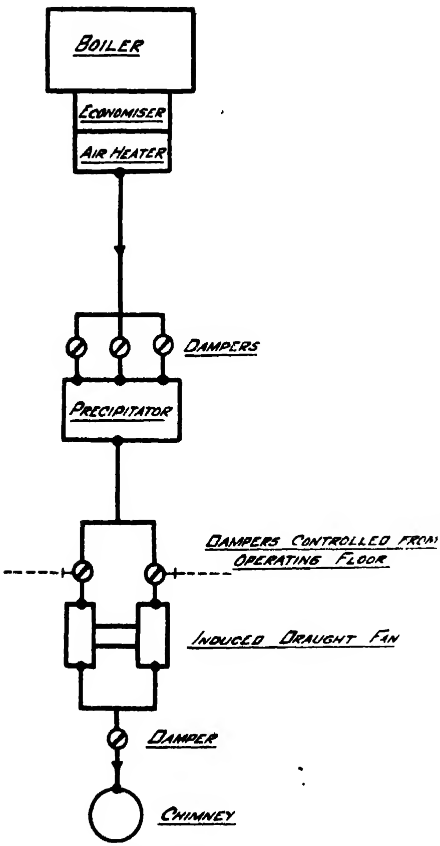


FIG. 158. Gas Circuit—Pulverised Fuel Boiler.

The secondary air fans are arranged in the most convenient positions having in mind the requirements of space and routes for hot air ducts. Fans at operating floor level are better from an operation point of view, but may result in a crowded lay-out unless floor space is available. Fans at operating floor and basement levels facilitate inspection and maintenance of motors, fan runners and equipment. If the I.D. fans are placed on an upper floor it is necessary to eliminate any possibility of back-draught during banking conditions for cases are on record where grates (both chain and retort) have been severely burnt from this cause. To overcome this, large doors are provided in the wind box or ducts leading from it which can be opened during banking. An alternative is to run an I.D. fan at low speed, but this increases the works auxiliary power.

Wherever they are situated, lifting and transporting gear should be provided. With fans placed on the roof or an upper floor, large open wells will be necessary and the methods of transporting the auxiliaries in case of replacements becomes a point of importance. Goods lifts are able to handle reasonably large and heavy loads.

Consideration must also be given to the layout of draught plant in so far as it affects the design and construction of the boiler house building. Much time can be saved in the early stages of construction if a layout which is independent of the building frame-work can be obtained. If vanes and dust collectors are fitted to the fans the control gear and operating valves should be disposed to permit of easy access for operation and maintenance. Control of F.D. and I.D. fans is carried out from panels on the operating floor.

A feature of importance is the layout of the I.D. fans in relation to the flue gas cleaning and washing plants. The fans are placed after the dust precipitators and arresters to reduce blade erosion or sand blasting. Abrasion resisting materials have been developed for fan construction. Vitrified steel plate resists erosion but it is rather expensive. The benefit derived by placing the fans after the dust arresting plant will be gathered from the following case :—

Fans placed before electrostatic precipitators—blades required replacing after two years.

Fans placed after electrostatic precipitators—blades lasted indefinitely.

When flue gas washing plant is installed the fans are situated between the outlet of the sulphur extraction plant and the chimneys and are self-cleaning. This position also brings about a considerable saving in power due to the drop in temperature of the flue gases. Some objections to the fans being on the outlet side of the extraction plant are :—

(1) Corrosion of the fan impellers and casings due to the moist atmosphere of the flue gases.

(2) Attack from the chemical action arising from the process.

(3) Deposits on the impellers when the gas temperature approaches the dew-point.

Self-cleaning fans are desirable since they are subjected to a carry-over of fine wet particles together with minute particles of grit which tend to adhere to the impellers, causing out-of-balance. Jets and sprays in the fan casing keep the impellers free from deposits of grit, etc., but out-of-balance still occurs after long periods of operation. It is also found that the carry-over is both erosive and corrosive and in due course attacks the impellers and spray nozzles. Rubber-covered impellers have been tried, but the methods of attaching the rubber are not too successful. Wearing strips with beads welded across the face have been welded to the blades at the centre plate, where most of the wear is found to concentrate.

FLUE GAS CLEANING AND DUST EXTRACTION PLANTS

The subject of flue gas cleaning has become a problem of prime importance in the design of large power stations. A station in or near a city or large residential area must not be a nuisance, particularly insofar as the discharge of soot, grit and sulphur from the boiler chimney is concerned. However, the mere fact of placing a station in the country does not exempt it from this condition, since much damage could be done to agricultural crops, etc. There are on record claims which have been made against electricity undertakings for such damage ; on the other hand, crops have been improved on land in the vicinity of power stations. The discharge of soot and grit alone would be an intolerable nuisance with stations burning from 2,000 to 7,000 tons of coal per day. The emission of grit from power station chimneys may be due to a combination of many circumstances including overloading of boilers, working boilers for long periods in a dirty condition, using unsuitable coal, very low chimneys, incorrect firing and inefficient operation of grit-arresting plant. An undertaking may, during emergency conditions, be obliged to operate a station at its maximum capacity for long uninterrupted periods and may have no control over the coal burned or selected. Pulverised fuel plants may give cause for annoyance if the precipitators trip out even for very short periods. It has been known for the surrounding property to be covered with a fine dust and when rain falls this quickly becomes sludge.

It may be possible to improve the quality of the coal and make arrangements to segregate the various classes of coal so that they may be identified on arrival at the station and used accordingly. Separation of the high and low volatile coals and the better blending of the many varieties comprising each of these classes will also assist in this direction. It would appear that the treatment of coal at the mine would be most desirable and effective. The washing of flue gases to meet the requirements of the local health authorities has been largely responsible for the development of some ingenious combinations of mechanical, electrical and chemical engineering. In one instance the limits specified were that the gases leaving the chimneys should not contain more than 0·03 grain of sulphur per cubic foot. The gas washing schemes in operation at the present time for the removal of sulphur depend on the use of some form of alkali and in which some solid residue is produced. The alkalis required for the process exist in river water, and if sufficient river water is available they can be readily obtained. It is doubtful whether

any of our rivers have sufficient water to enable this being done for a large station. In any case the effluent produced in its present state could not be discharged to a river, as river authorities usually stipulate that under no circumstances must reducing matter enter a river. Flue gas washing has been applied to a number of base-load stations and satisfactory results are being maintained. Every endeavour is made to utilise coal with a high calorific value and a sulphur content exceeding very little more than 1 per cent. In one station the efficiency of the plant will be appreciated from the fact that instead of the guaranteed figure of 0·03 grain of sulphur being

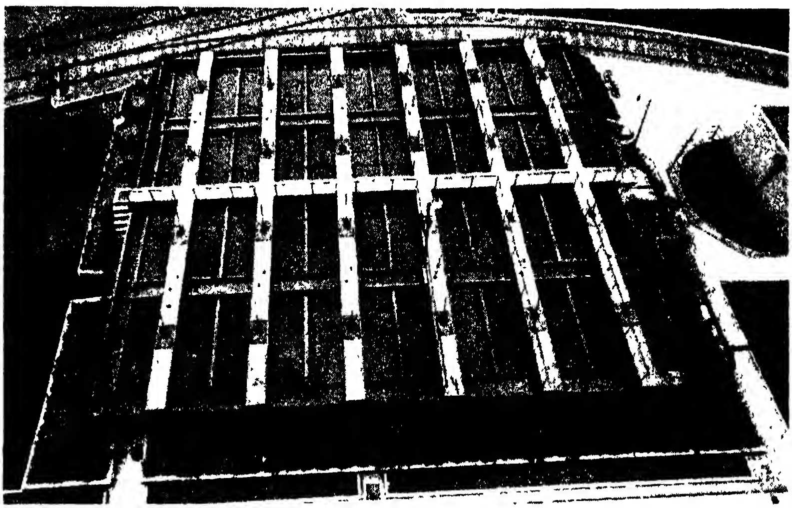


FIG. 159. Filter Plant in connection with Flue Gas Washing Plant, Battersea Power Station.

obtained it is generally as low as 0·006, whilst only mere traces of dust less than 5 microns in size are discharged with the gases to the atmosphere. Pipes, tanks, pumps, etc., are lined with rubber to prevent damage from corrosion and erosion. Special chrome steel impellers appear to give better service than those covered with rubber. A filter plant is illustrated in Fig. 159. The testing of flue gases for sulphur content is important and a suitable instrument has been developed which records the percentage of SO_2 in the chimney gases continuously over twenty-four hours. The dry sulphur extraction process has not yet reached the commercial stage but research is still proceeding in this direction. The flue gas washing plant of the oil-fired station at Bankside is of interest.

separated and the clean gases returned to the eye of the fan. Since the extraction efficiency of any centrifugal collector is a function of the pressure drop across the equipment the degree of extraction will often be limited by the power requirements which are proportional to the pressure drop. Where vane control is used the efficiency of dust collection is increased as the vanes are closed. By closing the vanes the pressure difference between the scroll proper and fan inlet is increased, resulting in increased collecting efficiency.

There are other types of dust collectors embodying the cyclonic principle which are placed on the inlet sides of the fans to reduce blade erosion. In one type there may be three collectors per fan

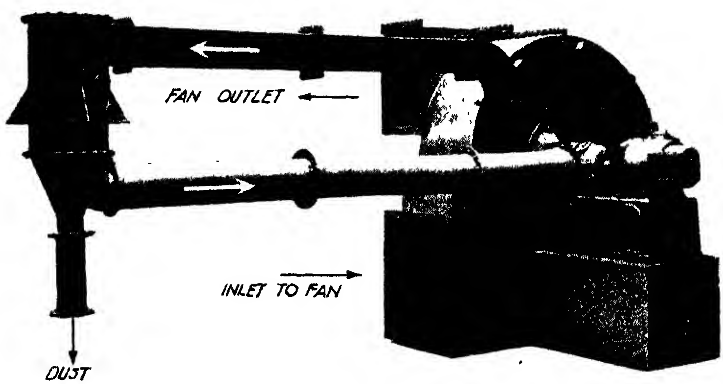


FIG. 160. Grit Arrester on I.D. Fan. (J. Howden & Co. Ltd.)

operating in parallel, the separated dust dropping into air tight bins from which it is periodically extracted. The equipment consists of a main casing of volute shape provided with an inlet through which the dust-laden gases enter tangentially. The dust-laden gases thus entering the equipment are forced by their velocity to take a path following the periphery of the volute. The dust particles, being heavier than the gases, are forced outwards towards the periphery, and as the action of separation is centrifugal the separating effect increases as the radius of the volute decreases. The particles have a fairly long path to traverse in a spiral and downward direction through cones and cylinders to the dust outlet at the bottom. This gives the lighter particles a chance of coming under gravitional as well as centrifugal influence and they are therefore more easily

caught. The clean gases form a vortex in the centre of the chamber and pass upwards through the outlet.

The mechanical dust collectors may have partitions to permit efficient operation at partial loads. Multi-cell centrifugal dust extractors are often installed between the economisers and the air heaters.

There are few water spray or water film types due to the nature of the plant required for disposal of the residue, the need for brick or concrete chimneys, a supply of suitable water and high initial cost and maintenance charges.

Electrostatic precipitators are adopted for the extraction of dust and grit from the flue gases of pulverised fuel boilers. Some plants are provided with both mechanical and electrostatic dust extraction equipments. Under ordinary working conditions the concentration of dust in the exit gas from stoker-fired boilers may be from 0·5 to 1·5 grains per cubic foot, depending on the ash content of the coal. With pulverised fuel similar conditions result in 1·5 to 4 grains per cubic foot. During soot blowing the quantity may be increased five to ten times. The cleaning of flue gases by electrostatic precipitation depends upon the principle that when a gas containing solid or liquid particles is passed between two electrodes, one of which is charged to a very high potential and the other earthed, the particles or dispersoids in the gas are driven to the earthed electrode and removed from the gas stream. The actual removal of the particles from the gas is caused primarily by the ionisation of the gas as it passes between the electrodes. Ions are formed near the discharge electrode and move across the gas stream to the receiving electrode. The efficiency of a precipitator can be made to approach 100 per cent., but for flue-gas cleaning 90 to 99 per cent. is usual. The size and cost increase with high efficiencies.

In calculating the efficiency of precipitation it is generally assumed that :—

(1) The quantity of dust deposited on a given spot is proportional to the dust density existing in the gas at that spot.

(2) The dust particles drift on to the collecting electrode at a constant velocity which depends on the particle size.

There are two forces acting on a particle having directions at right angles to each other. The first is that set up by the flow of the gas which carries the same particle along between the two electrodes and the second is that produced by the ionisation of the gas and particles and is on a plane at right angles to the plane of the electrodes. Or, in other words, the path of a particle will

take a direction which is the resultant of the gas velocity and the force set up by the electrostatic field. It is the resultant of these two forces which moves the particle across the space between the electrodes and the path assumed is similar to that indicated in Fig. 161. In this view it is assumed that the receiving electrode is a vertical tube and the discharge electrode is a fine wire suspended centrally in the tube with the path of the gas being vertically upward. If a particle becomes ionised at point A (and the precipitator is correctly designed), it will move over a path to point B which is on the tube wall. If, however, the gas velocity in the tube

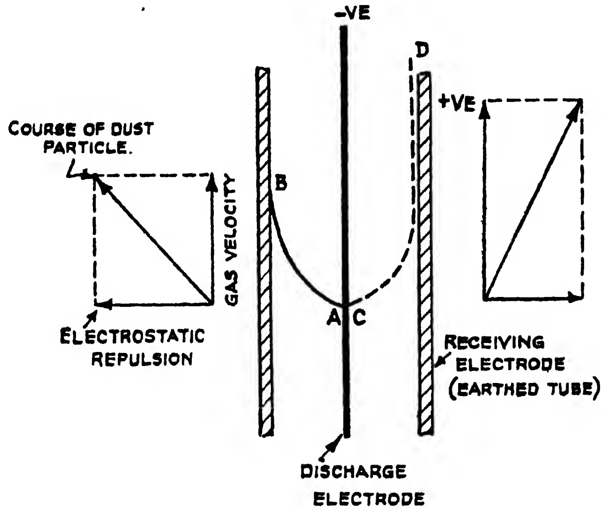


Fig. 161. Path of dust particle.

is too high, or conversely the voltage (and consequently the ionisation effect) is too low, the particle will assume a path from C to D, in which case it will be carried beyond the end of the tube and escape. The electrodes from which discharge takes place are of negative polarity ; the dust particles thus become negatively charged by bombardment of the electrons in the ionised gas and are repelled by the negative electrodes and deposited in the positive receiving electrodes which are at earth potential. Electrostatic precipitators are of the plate and tube types. In the former the gas moves either vertically upwards or downward or horizontally between rows of parallel plates, with discharge electrodes suspended centrally between each pair of plates. Precipitators with perforated-plate electrodes have been used with satisfactory results. In the tubular

type the tubes always hang vertically so that the gases can only pass up or down. The discharge electrode hangs centrally in each tube and for good ionisation it should be made of fine wire, the smaller the wire the greater the intensity of ionisation of the gas. Each electrode, being very fine wire, should be held taut by a heavy weight suspended at the bottom to keep it central and prevent oscillation. If free, the electrodes would vibrate with great rapidity when charged to a high potential, enough to produce a corona or precipitation effect. The amplitude of this vibration is considerable and would result in flashovers between the oscillating wire and

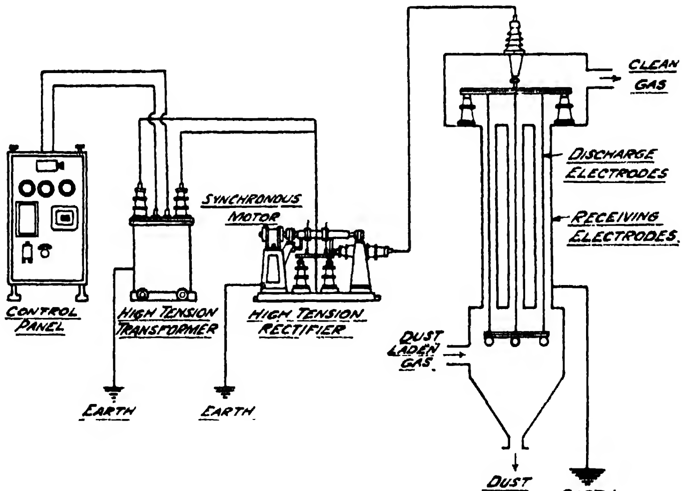


FIG. 162. Simplified General Arrangement of an Electrostatic Precipitation Plant. (Sturtevant Engineering Co. Ltd.)

earthed tube. The primary cause of swing is the uneven or unbalanced forces between the two electrodes, and since the receiving electrode is fixed the forces naturally cause the discharge electrode to oscillate. This may be eliminated by tying the discharge electrodes together at the bottom ends. The discharge electrodes are of square section wire since this combines the essentials of good corona discharge and high mechanical strength. The four corners of the electrode provide what is in effect a series of points from which a very intensive discharge is obtained, and by twisting the wire the strong points are spread in all directions around the electrode. The general arrangement of a tubular precipitator is shown in Figs. 162 and 163. The receiving electrodes are made up of

hexagonal tubes nested together in honeycomb fashion, a number being placed in each bank. The discharge and receiving electrodes must be kept clean if good operation is to continue. This is done by two sets of rapping gear, one for the discharge electrodes and the other for the receiving electrodes. The accumulation of dust on the discharge electrode increases its diameter with consequent drop in

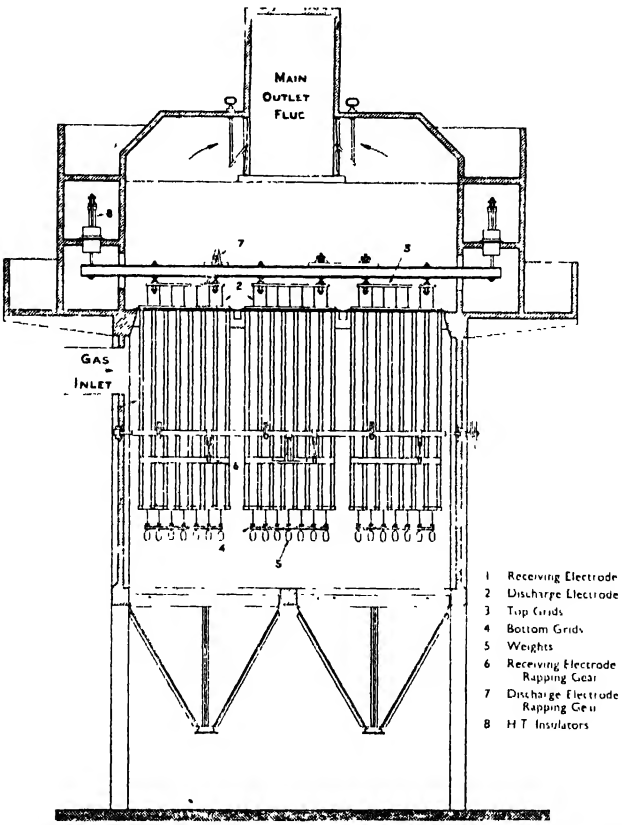


Fig. 163. Sectional Arrangement of Precipitator to operate at moderate Temperatures. (Sturtevant Engineering Co. Ltd.)

voltage intensity, and the receiving electrode with a coating of deposited material, especially if it is non-conductive, produces back-ionisation. The square wire used for the discharge electrodes is flexible and the blows imparted by the rappers easily make the wires vibrate throughout their length, causing them to free the dust. The receiving electrode tube banks are vibrated throughout at each knock of the hammer and their dust deposits fall off. The dust is collected

in hoppers immediately below the casing. The hoppers have grids fitted to prevent falling lining or other materials choking the outlet. All internal insulators for supporting the high-voltage electrode systems are of fused silica. The surfaces of the supporting insulators should be cleaned at regular intervals. Where precipitators are placed outdoors the entire sheet-steel casing should be lagged for if the dew-point of the gases is reached corrosion is inevitable. If the precipitators are placed indoors it may be possible to dispense with the external lagging, but if corrosion is to be prevented it is advisable to apply an internal lining. This is almost essential on one- and two-shift stations where daily starting up and shutting down is responsible for much corrosion trouble caused by low-temperature gases. The internal lining serves to prevent corrosion of the casing plates and acts as a heat-insulating medium. Reinforced concrete chambers are also used, and are constructed of aluminous cement concrete as a protection against acids. The various types are given in Table 25.

TABLE. 25. *Comparison between various types of Dust Extraction Plants*

Type of Plant	Capital Cost	Operating Cost	Maintenance Cost	Space Occupied		Draught Loss
				Area	Volume	
Water film (with Settling Tank) . . .	1·0	1·0	1·0	1·0	1·0	1·0
Ditto (with Filter Plant)	2·0	2·0	2·0	0·5	1·7	1·0
Combined Water Spray and Film (with Settling Tanks) . . .	1·1	1·0	1·0	1·5	1·8	1·3
Combined Water Spray and Film (with Filter Plant) . . .	2·0	2·0	2·0	0·9	2·5	1·3
Electrostatic. . .	1·9	2·0	0·5	0·45	3·0	0·33
Multi-cyclone . .	1·1	1·0	0·6	0·40	3·5	2·8

Wet Systems. The advantages will be observed from Table 25. Some disadvantages are :—

(1) Corrosion may be experienced unless chimney has an acid-proof lining.
(2) Disposal and filtering of the effluent.
(3) The cooling of the gases in the chimney causes draught loss.

Dry Systems (Electrostatic)

(1) Flue gases do not come in contact with water.
(2) The draught loss is small.
(3) Maintenance costs are reasonably low.
(4) The dust is collected dry and can be removed either dry or wet.
(5) Heat loss in flue gases is small.

Some of the disadvantages are :—

Larger space occupied than the "wet" systems, the efficiency is not maintained if the gas velocity exceeds that for which the plant is designed, and high capital cost. The supply to the precipitator is very high voltage direct current, 30 to 60 kV. The methods of obtaining this direct current supply are :—

(1) Series combination of d.c. generators.
(2) Mechanical rectifier (disc or blade type).
(3) Metal or copper oxide rectifier.
(4) Valve rectifier.

The valve rectifier is too fragile for industrial purposes. The electrical equipment for the first method may consist of three or four d.c. machines, each provided with a double wound armature and two commutators connected in series to produce direct current voltage of 40 to 60 kV. A third commutator is fitted to each generator to deliver exciting current at low voltage. The bases of these machines are insulated from earth but the frames are at a potential equal to the average voltage between the two H.T. commutators fitted to each armature. The machines are coupled by means of insulated couplings. The prime mover (a.c. or d.c. motor) may drive one, two or three generators in series, the positive pole of No. 1 set being connected to earth and the negative pole of the third set taken to the precipitator discharge electrodes.

The mechanical rectifier with rotating blades has been used on numerous plants and Fig. 164 shows a typical layout. There are two blades keyed to an insulated shaft and driven by a synchronous motor, the motor having a movable stator which is operated from outside the screened area. This type of stator makes it possible to synchronise the rectifier with the current supply and conduct off at the most suitable parts H.T. current and voltage waves. The blades are provided with a tip on both ends and a copper ring, mounted on the shaft, with a brush making a final connection to the precipitator or to earth. Two pairs of shoes on both sides of the rectifier are connected to the terminals of the step-up transformer and here again, as the blades rotate, the negative current is conducted from the shoes by the blade tips and passed to the precipitator *viâ*

the blades themselves, the copper rings and brushes, and the bushing at the end of the rectifier. Since one brush is connected permanently to the precipitator and the other to earth the circuit is

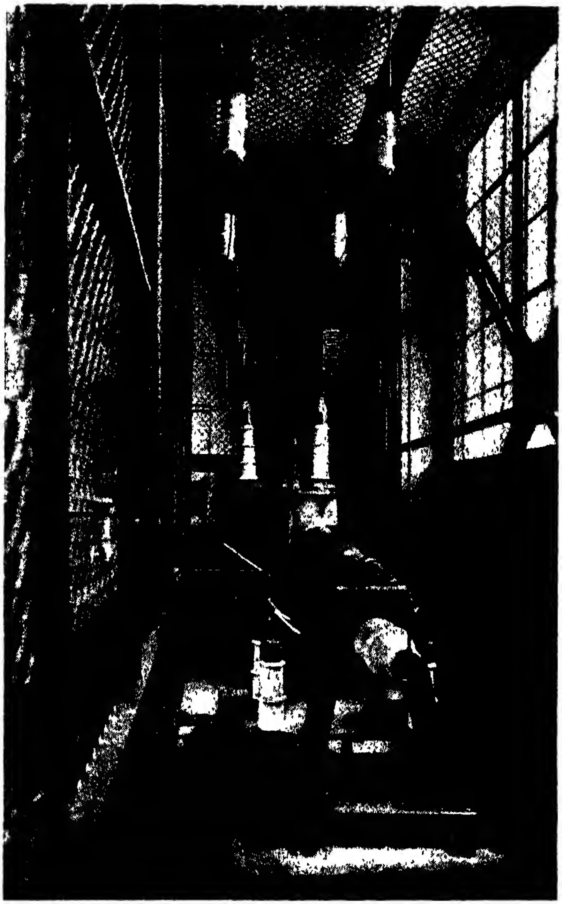
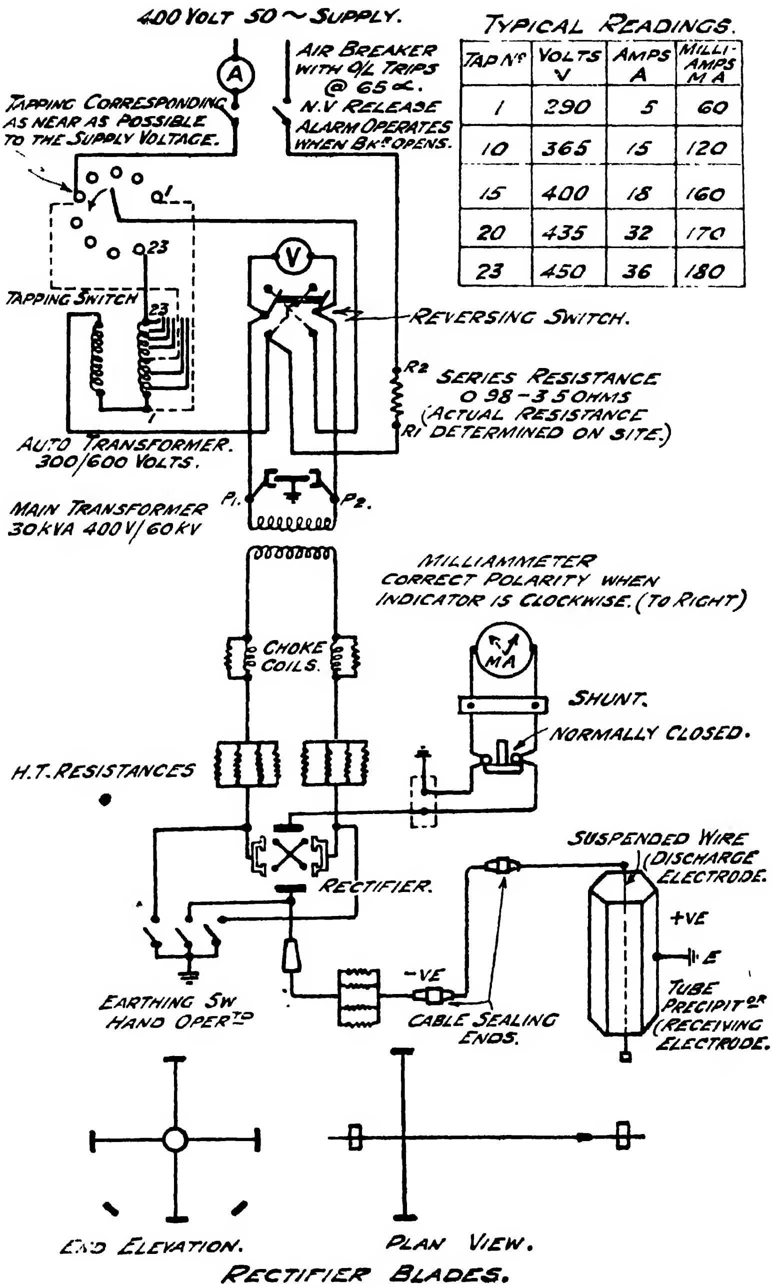


FIG. 164. High Tension Plant for Electrostatic Precipitator, Derby (Sturtevant Engineering Co. Ltd.)

completed in the same manner as on the disc machine. Figs. 165–167 give connections and data appertaining to such plant.

A milliammeter of the centre zero type is connected in the high tension circuit which in addition to giving current indication also shows the polarity. When correct polarity is obtained a blue spark is usual at the brushes whereas incorrect polarity is accompanied by



TYPICAL READINGS.

TAP No	VOLTS V	AMPS A	MILLI-AMPS MA
1	290	5	60
10	365	15	120
15	400	18	160
20	435	32	170
23	450	36	180

FIG. 165. Main Connections of Electrostatic Precipitator.

a green spark. A reversing switch in the low tension circuit of the transformer enables correct polarity to be obtained. A discharge across the milliammeter pointer causes discoloration of the scale plate and in time the meter is rendered useless.

The metal rectifier has an advantage in that there are no moving parts. It is made up of a number of copper discs coated with oxide, the oxide film presenting a high resistance to current flowing in one direction but allowing it to pass in the other. In this way the pulsating a.c. is rectified to unidirectional current. The copper discs are mounted on a spindle from which they are insulated and fins are used to radiate the heat generated by the passage of current. With this apparatus a high tension transformer is required in the same way as for the mechanical rectifiers. All types of precipitators

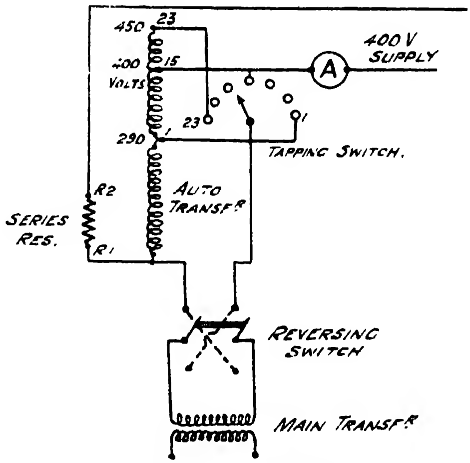


FIG. 166. Simplified Diagram of L.T. Connections.

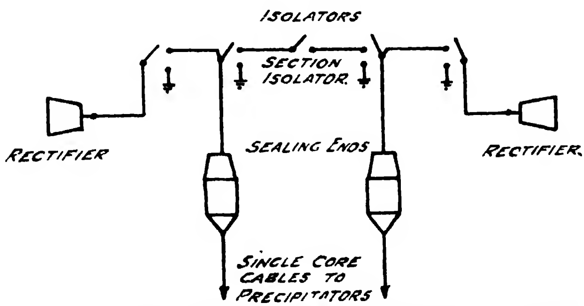


FIG. 167. Two Precipitators arranged for working off one Rectifier.

and their high tension sets are mechanically (and sometimes electrically) interlocked so that it is impossible for operators to enter any danger zone until all current has been switched off and the plant earthed. This earthing is necessary since a precipitator is, in effect, a large condenser, and cutting off the current supply does not make the plant safe to enter. The electrodes hold a considerable charge

which may be dangerous and an interlocked earthed switch and access doors are essential for safety. To eliminate the possibility of accidents the supplies for the main unit and auxiliaries (rapping gear drives, etc.) should be controlled from one switch. Wireless interference is minimised by enclosing the whole of the H.T. equipment in a screened chamber of steel wire or expanded metal.

Some features of electrostatic precipitators are :—

(1) Very little trouble from discharge electrodes fracturing or insulator failure.

(2) So long as the boiler is under reasonable load, say from quarter load up to M.C.R., no trouble is experienced with circuit-breaker tripping due to flash over in the precipitator. This is quite a usual occurrence when starting a boiler from cold or when shutting it down suddenly, due to sudden changes in the gas composition.

(3) The power consumption working with a 200,000 lb. per hour boiler is about 11 kW. for the H.T. equipment and 2 kW. for motor drives.

(4) Rectifier shoes and blade tips and rapper arms and pins occasionally require replacing.

(5) Only protective gear required for plant is the no-volt and overcurrent releases on the main breaker. Sustained flashing causes the latter to operate.

(6) Trouble is sometimes experienced due to drainage of oil from the cable sealing ends. A high leakage discharge due to this is noted on the milliammeter.

(7) Labour operating charges are small.

(8) High resistance leakage paths cause erratic operation of the rectifier and result in heavy sparking of a surging nature. Such fluctuations of current will be observed on the main L.T. ammeter. Persistent shorting on the H.T. side will cause the series resistance to overheat.

(9) The ozone and nitric acid in the rectifier chamber atmosphere has deleterious effects on the instruments and surrounding metal work. Galvanising is essential for all steel work whilst instrument bearings, etc., deserve special attention.

The following data relates to a precipitator for boiler unit of 130,000 lb. per hour steaming capacity :—

Floor area : 600 sq. ft.

Building space : 22,500 cubic ft.

Rapping gear for discharge and receiving electrodes : Two motor-driven equipments, each 1 B.H.P.

Mechanical rectifier (blades) : Synchronous motor 1·5 B.H.P.

Transformer : Single phase type ON—30 kV.A., 400 V./60 kV.
Auto-transformer : 300/600 volts.
Draught loss through precipitator : ½ in. W.G.
Efficiency : 94 to 96 per cent.

Electrostatic precipitators do not appear to operate satisfactorily if they are too small, gas velocities are too high and the plates or tubes are not rapped fairly frequently or at other than partial loading. In one plant the electrostatic precipitators had a guaranteed efficiency of 98 per cent. at maximum continuous boiler rating when handling 142,500 ft. of gas per minute. On test the actual efficiency obtained approached 99·4 per cent. Further test results are given in Chapter XX, Vol. 2.

Dust Removal. Various methods are in use, some of which are :—

(1) Vacuum extraction plants.
(2) Water ejector systems.
(3) Discharging dust direct to sluices by chutes.
(4) Discharging into conveyors.

Vacuum plants are used on both stoker and pulverised fuel installations and give good service. The plant consists of a primary receiver, secondary cyclone receiver, water or cloth interceptor and motor-driven turbo-exhauster. Two equipments can be worked simultaneously from one primary receiver. Valves of the flat slide type are fitted to the hoppers and bins, to allow air to pass into the piping system before the orifice connecting the dust hoppers is opened. This ensures that the air stream is in action before dust commences to fall. Precautions are taken to reduce the abrasive action of the dust at the bends and junctions in the piping system. Special wearing plates have been used for bends where abrasion was not too severe. It has been suggested that right-angle bends are better than " easy " bends, since the corner is in time made up with grit and serves to prevent excessive wear. This has been tried on boiler plants using coal and coke and proved successful. All bends were of the right-angle type and replacements were negligible after continuous service extending over five years.

The primary receiver is a cylindrical steel vessel designed to withstand the collapsing effect of the vacuum and having a holding capacity to suit requirements.

The secondary cyclone receiver is included to arrest the fine dust carried over from the primary receiver. The water interceptor is in the form of a cylindrical steel vessel having a head of water through which the air is passed to extract the fine residue of dust which

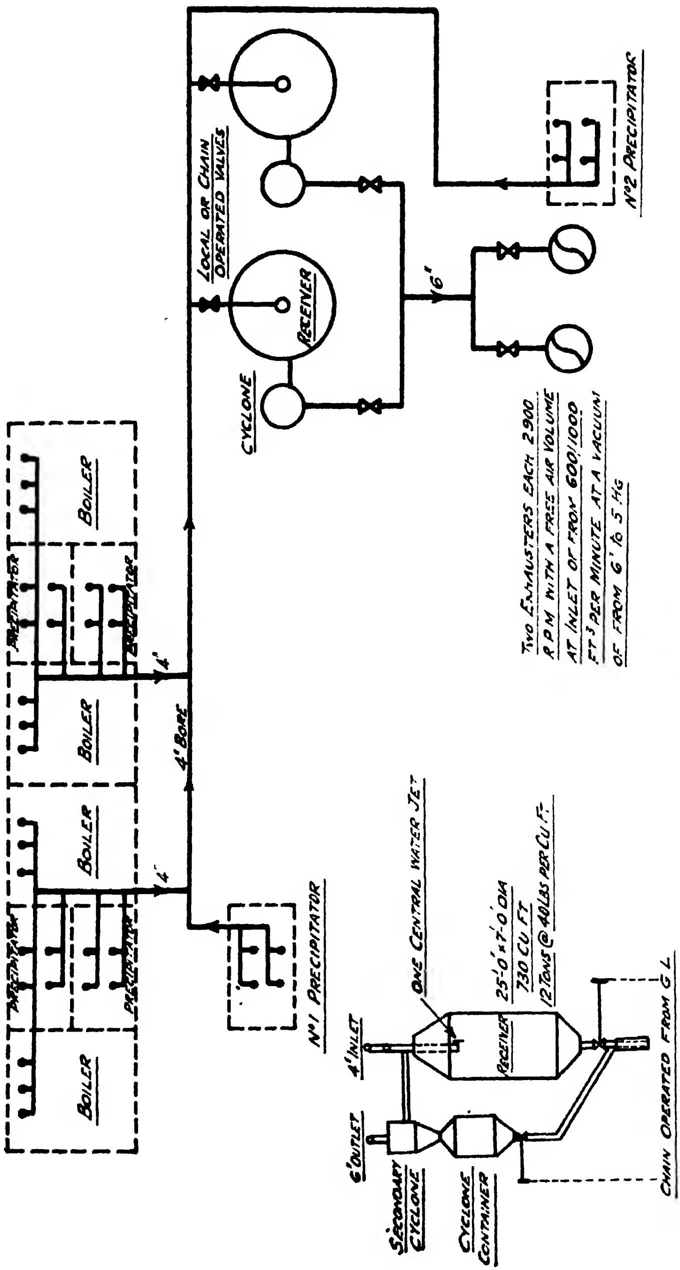


FIG. 168. Pneumatic Flue Dust Plant for Pulverised Fuel Boilers.

remains before passing into the exhauster. In some cases cloth or bag interceptors are used. The exhauster provides the necessary air volume and suction for handling the required amount of dust. Diagrammatic layouts are shown in Figs. 168 and 169.

The water-ejector system has also been used on both stoker and pulverised fuel installations and if the ash-handling plant is such that high-pressure water is required then its adoption is worthy of consideration. The dust is periodically extracted from the hoppers by the water ejectors. These ejectors have a very positive suction action and can pull the dust out of the hoppers at the rate of 60 to 80 tons per hour and discharge it into a sluiceway in the form of a completely wetted-down slurry. Steam ejector systems have also

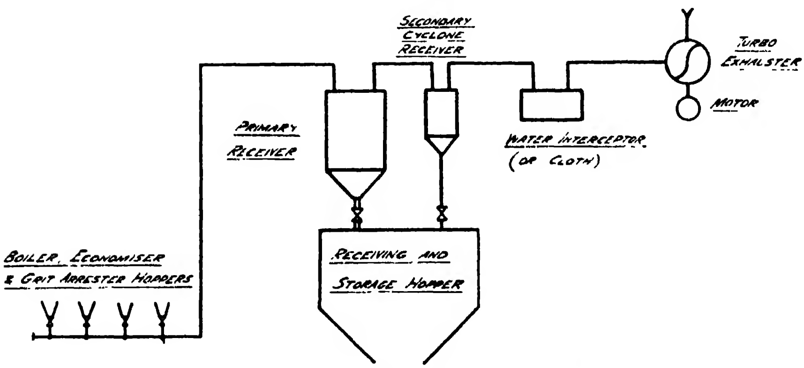


FIG. 169. **Pneumatic Flue Dust and Grit Extraction Plant.**

been used. The use of screw and " Redler " conveyors may also be adopted to deliver the soot and grits to overhead bunkers.

The disposal of this dust, particularly when pulverised fuel is used, becomes a serious problem and may cause considerable inconvenience to surrounding property unless precautions are taken to wet it before handling. One successful method is to provide a mixing screw conveyor at the outlet of the container.

Use has been made of pulverised fuel dust for stone-dusting in coal mines, the dust being collected in bags and then sent underground. The pipes, etc. may require lagging; as water vapour carried over may cause choking of pipes. Trouble has been experienced with the ash where dust is discharged to a common sump, due to settling out difficulties in the sump. In pulverised fuel plants a considerable quantity of the dust is made up of hollow spheres which are able to float and may sometimes cover a depth of about 2 ft. from the water surface. The dust or fine ash which does

settle out may cause the bulk of the ash in the sump to set hard after a few hours and make it difficult for handling by grab.

The particulars given in Table 26 show how the deposition of dust takes place throughout a boiler unit at normal and maximum continuous ratings.

TABLE 26. *Dust Particulars*

Type of Boiler	Stoker		Pulverised Fuel	
Boiler rating—evaporation lb. per hour.	N.E.R. 150,000	M.C.R. 187,000	N.E.R. 110,000	M.C.R. 130,000
Catch from boiler and economiser hoppers—lb. per hour	70	100	150	180
Catch from grit arresters—lb. per hour	100	150	1,600	1,950
Catch from chimney hopper—lb. per hour	30	50	350*	420*
Total	200	300	2,100	2,550

* This includes all hoppers in ducts, etc. The amount collected at the chimney base is only a small proportion.

Flue dust varies in density, ranging from 15 to 55 lb. per cubic ft., being lighter at the chimney end. The combustible loss of this separated fine dust varies considerably and may be anything from 4 to 12 per cent., the total loss being less than 1 per cent. of the coal burned. These figures are only estimated values and depend largely on the thermal, chemical and physical characteristics of the coals. The stoker boiler I.D. fans have secondary vortex collectors and the pulverised fuel boiler an electrostatic precipitator.

Another method of clearing the economiser hoppers is to employ small extraction or grit re-firing fans. These extract the grit from the hoppers and return it to the combustion chamber by way of nozzles for re-burning. Sand blasting of the front walls, particularly if refractory construction, may be experienced.

The fly-ash of pulverised fuel boilers may be re-introduced into the combustion chamber where it is fused and discharged by way of the slag taps.

FLUE GAS DUCTS

The majority of ducts in use are of mild steel plate, although brick and concrete flues are quite often employed where the plant layout permits of these being adopted. Mild steel plate ducting covered with heat-insulating materials is not entirely satisfactory,

as expensive repairs and maintenance charges have been incurred in many plants owing to the inevitable corrosion which takes place with the low exit-gas temperatures now obtaining. These temperatures are responsible for the formation and deposition of moisture in the ducting and, together with the sulphur-content in the gases, result in deterioration of the steel plates. Attention has been

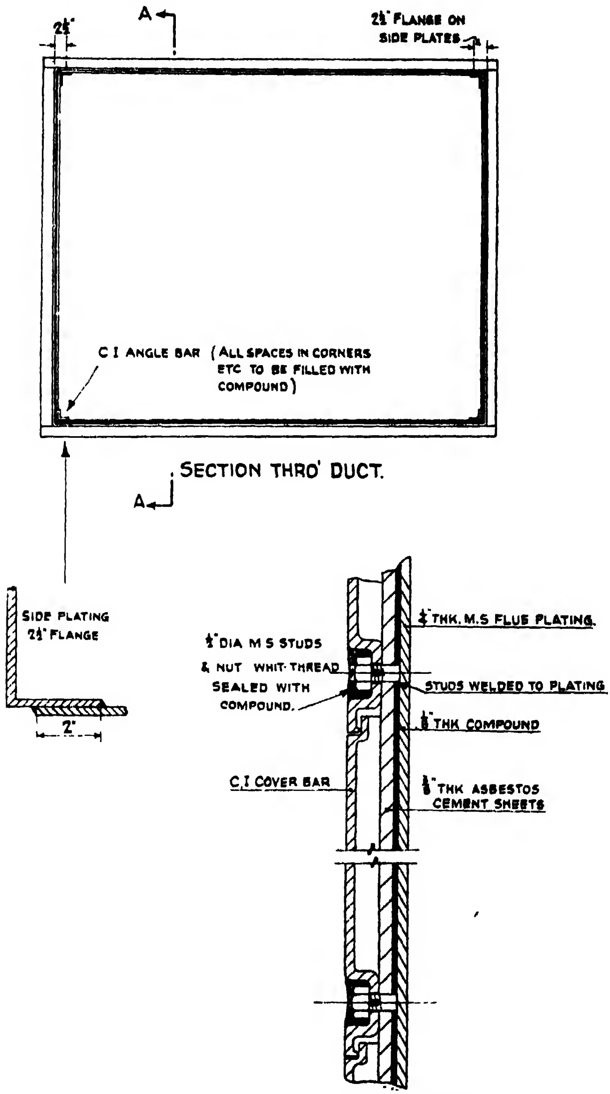


Fig. 170. Flue Gas Ducting Details.

directed to the use of internal protective linings for both steel ducts and steel-plate chimneys. The cost is higher, but in practice appears to be justified. Figs. 170 and 170A show one form of construction

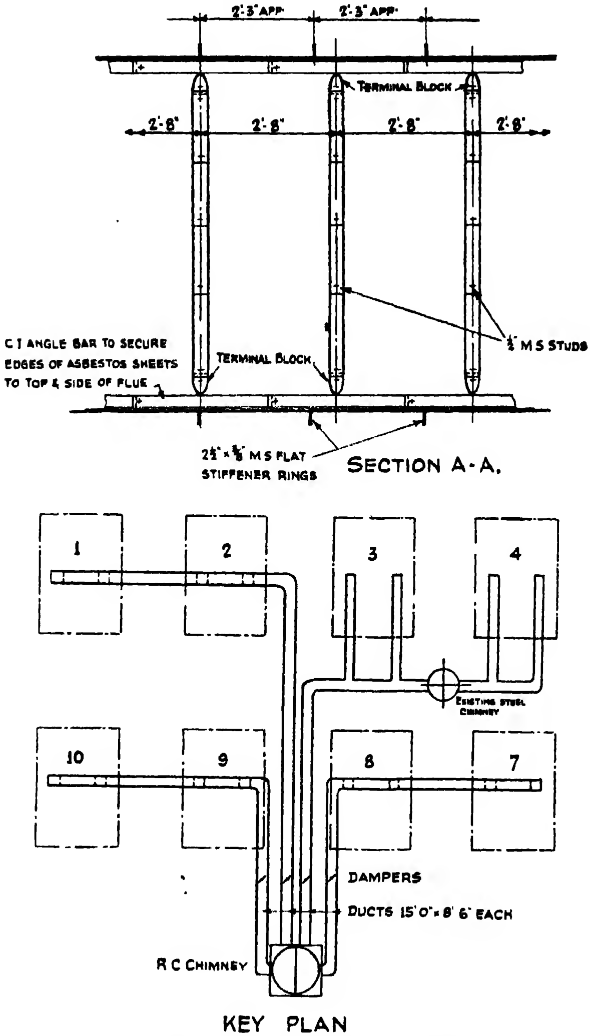


FIG. 170A. Flue Gas Ducting Details.

adopted. The lining consists of pre-formed bitumenised asbestos sheets set in a mastic compound and held with multiple cast-iron clamps which allow the normal flexure to occur without damage (also see Air and Gas Ducting and Steel Plate Chimney).

CHIMNEYS

Steel chimneys are still used but corrosion troubles are common and various methods of minimising these have been tried. Steel chimneys used on older boiler plants were trouble-free in so far as corrosion was concerned, and it can only be concluded that the troubles now experienced are due to low exit gas temperatures. Further, the trend towards higher chimneys also tends to accentuate the cooling of the gas stream in contact with the inner wall of the chimney and intensify internal corrosion. These low temperatures are responsible for the formation and deposition of moisture in the chimney and together with the sulphur content in the gases result in deterioration of the chimney plates. Air heaters bring about a reduction in flue gas temperatures, whereas in the earlier plants the gases entered the chimneys at fairly high temperatures. The higher flue gas temperature enabled the gas to be discharged without the strata in contact with the steel being cooled to fall below dew-point. Flue gas contains the corrosion-producing properties of air plus moisture from the fuel and sulphur. Sulphur products are very corrosive and in addition elevate the dew-point of the gas. The design of chimneys may be governed by local by-laws and these should always be considered before proceeding with the detailed design. A block plan showing the proposed position of the chimneys in relation to surrounding property together with a detailed drawing and full calculations may have to be submitted for approval. Probably the feature to which attention has been chiefly directed, apart from corrosion, is the chimney height. Much depends on the site, particularly the contour of ground, surrounding buildings and other obstructions. Any solid matter which may be emitted from a chimney should be dispersed over a wide area. To ensure this being done it appears that the height of a chimney should be at least two to three times the height of the highest obstruction of the station buildings. An external ladder of the safety cage or other approved type is provided to facilitate inspection and maintenance. Life-lines and pulleys are sometimes included, but steeplejacks do not place much faith in this equipment. To provide for testing chimney gases openings of suitable diameter may be provided at specified positions in the chimney or ducting. Where two outlet ducts enter a chimney and are opposite each other, a midfeather is necessary to direct the incoming gases up the chimney, thereby facilitating exit and minimising turbulence and churning. Doors for access to hoppers and the base of the chimney should be included. A suggestion put

forward is that very large chimneys should have a hoist incorporated as a permanent fixture. The internal linings of chimneys require attention and factors of importance are :—

(1) Abrasive action of the flue gases necessitate a hard or tough material.

(2) Sulphur and moisture are always present and the combination produces rapid corrosion. The lining should therefore be non-hygroscopic and be maintained intact.

(3) The lining should be sufficiently flexible to allow for chimney movement in very high winds, and also take care of temperature strains.

Lightning conductors for chimneys are discussed in Chapter XVIII, Volume 2.

Principal Dimensions. Before proceeding with the detailed design of a chimney it is necessary to fix the height and internal diameter. Certain recommendations have been put forward by the former Electricity Commissioners, and reference should be made to the 1932 Report drawn up by a Committee appointed by them. On p. 19 of this Report it is stated that :-

"The Sub-Committee conclude from this evidence that emissions from chimneys having a height of $2\frac{1}{2}$ times that of the surrounding buildings, plus, where necessary, additional height to compensate for the contour of the adjacent land, will discharge into an air stream which can be depended upon not to come in contact with the earth under normal conditions. The additional height required can be determined with a sufficient degree of accuracy by experiments with a model in a wind tunnel, or by investigations on the site with no-lift balloons."

The problems involved in estimating the behaviour of the plume from a chimney are rather complex. Professor D. Brunt, of the Imperial College of Science, London, carried out investigations, and his findings were published in *J. I. Elect. Engrs.*, Vol. 89, Part 2, June, 1942. In Professor Brunt's opinion, maximum gas concentration occurs at a distance from the chimney base equivalent to ten times the chimney height, and amounts to about 0·21 part per million by volume. This value is much lower than normal concentrations which occur in any industrial town and are regarded by Professor Brunt as innocuous. He considers that the concentration of fine grit follows the same laws, and is also innocuous provided that the emission from the stack is reasonably controlled. The highest building—excluding cooling towers—is usually the boiler-house.

In order to fix the internal diameter it is necessary to know the ultimate boiler capacity for which the chimney has to be designed. There is no degree of standardisation of flue-gas velocity in chimney

design, but it would appear that the average velocity ranges between 1,200 and 2,000 ft. per minute. Single chimneys have been designed for carrying the flue-gases associated with 120 to 150 MW of boiler plant with these gas velocities. In some cases the diameter of a chimney is governed by mechanical reasons or architectural proportions. The smaller the diameter the less will be the cost of both chimney and foundations. Although a saving can be effected by designing a chimney for weight and wind-pressure only, that is not recommended, because the vibrations come too near the dangerous limit for a very tall chimney. In fixing the height the draught produced is neglected, although some saving in induced-draught fan power is effected.

The technical data relating to one boiler plant are as follows :—

Steam pressure, 650 p.s.i. gauge, steam temperature, 850° F.

Average feed-water temperature, 305° F. ; $H_s - H_f$ = 1,154 B.Th.U./lb.

Average calorific value of coal, 11,500 B.Th.U./lb.

Average flue-gas temperature, 300° F. ; average CO_2 at chimney inlet, 11 per cent.

Corresponding flue-gas per lb. of coal, 15 lb.

Volume of flue-gas per lb. of coal at 300° F., 290 ft.^{3}

One boiler unit (180,000 lb. of steam per hour) requires approximately 21,500 lb. of coal per hour.

Eight boilers at 180,000 lb. per hour = 144 MW (assuming 10 lb. of steam per kWh.).

With eight boilers steaming at this rating, the approximate volume of flue-gas passing to the chimney would be 8 . 21,500 . 290 ft^3., and with a 22-ft. diameter chimney would result in a velocity approaching 2,200 ft./min. Six boilers normally operating at full load would give a velocity of about 1,650 ft./min. (27·3 ft./sec.) (see Gas Velocity).

Type of Chimney. The types in use are :—

(1) Steel plate. (2) Brick. (3) Reinforced concrete. (4) Aluminium.

Comparative costs of the various types are given :—

Unlined steel plate	1·0
Lined steel plate	1·3 to 1·5
Concrete (central, three boilers)	2·2 to 2·5
Brick (central, three boilers)	3·0 to 4·0

Some actual costs are :—

Unlined mild steel chimney	£2,000 (170 ft. high, 10 ft. diameter).
Lined—0·6 per cent. copper bearing mild steel	£2,800 (145 ft. high, 12 ft. diameter).
Steel chimney (asbestos-cement lining)	Lining only, £650.
Reinforced concrete (without acid-resisting lining)	£8,000 (340 ft. high, 27 ft. diameter average).

The cost of foundations is not included. Table 27 gives further data relating to brick and concrete chimneys.

Steel Plate Chimney. This is used when a separate chimney is employed for each boiler or for two medium-capacity boilers. It is cheaper, as erection time is reduced and the foundations are not so costly. The disadvantages are painting and maintenance charges due to the effects of corrosion.

The chimneys may be arranged in rows down the sides of the boiler house or be supported and anchored on the building and boiler steel-work down the centre of the boiler house. The layout will, of course, depend on the arrangement of the boiler plant.

Chimneys have been constructed of plates made of :—

Ordinary mild steel, copper-bearing mild steel, special stainless steel and "Armco" iron. Riveted and all-welded construction have been used.

The lap joints can be arranged to prevent lodgment of water and dirt on the outside although on unlined chimneys the inside laps have been suggested as giving better service since the joints are not subject to attack from sulphur and gas. With the inside lap joint any paint applied to the outside tends to seal the joints and form a water shedding fillet on the top edge of the stack plates. Where the chimney passes through the roof, cravat sleeves and roof plates should be included to ensure a weather-tight joint.

Plate chimneys are usually of circular section, although the ejector type has been adopted. Steel plate chimney details are given in Fig. 171. The chief trouble with steel chimneys is corrosion, which may occur both internally and externally, resulting in a gradual reduction in plate thickness. Should the plate thickness become unduly reduced, particularly in the lower sections of the chimney, the structure may collapse under its own weight. Every possible step should be taken to prevent undue wasting, and every chimney should be inspected annually.

Internal corrosion is attributed largely to the fact that so much heat is abstracted from the flue gases that the chimney temperature is reduced to a figure not exceeding 300° F. There is considerable condensation of the steam in the gases resulting in the formation of moisture which together with the sulphur and dioxides of carbon present, forms highly corrosive acids. Internal wasting will be minimised by use of coal having a low sulphur content but this is not always possible. The possibility of high dew-point temperatures should be kept in mind as the dew-point of sulphuric acid is over 600° F. It has been suggested that the flue gases adjacent to the

inner wall are cooled below dew-point and moisture from the gases is deposited on this wall. This moisture picks up sulphur from the gases, thus forming a dilute solution of sulphurous acid which

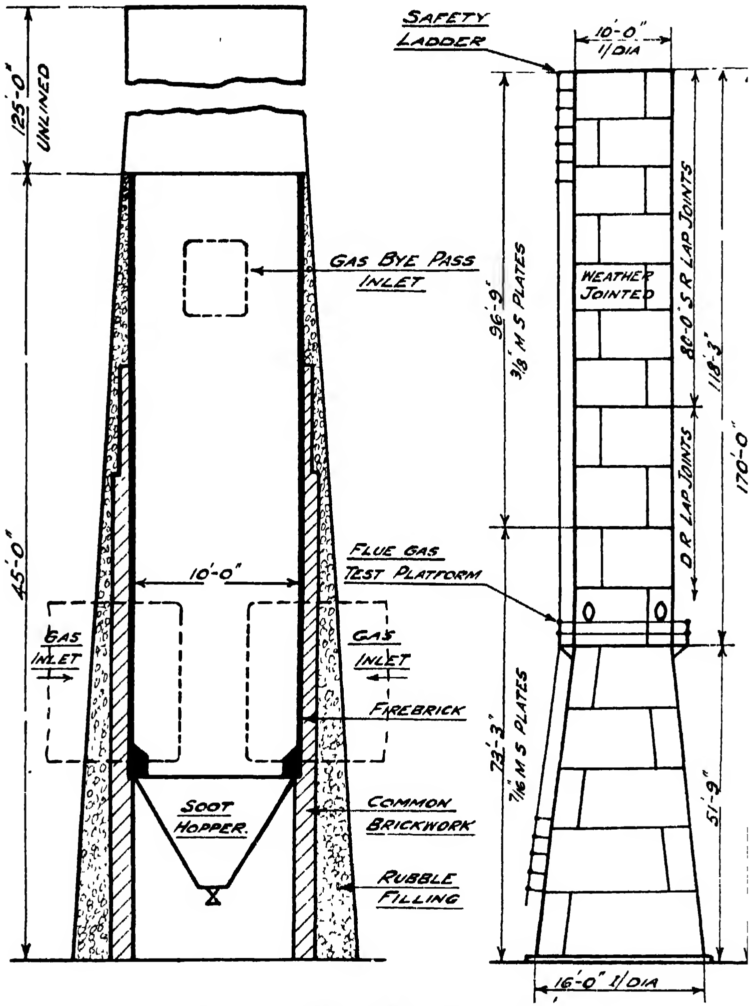


FIG. 171. Steel Plate Chimney Details.

causes rapid corrosion. Where the smoke issuing from a chimney is rather "steamy" it may be that there is a tube or joint blowing in the gas path. External corrosion is caused by climatic conditions and at the upper sections by the dioxides of sulphur and carbon in the gases in association with moisture, if the gases are blown down the outside

of the chimney. Painting the outside of the stack with oxide of iron paint, say every two years, or as soon as the old paints shows signs of peeling off, will guard against external corrosion.

Ducting from the induced draught fans to the chimney is also subject to corrosion and should be protected. In one instance the ducting to the chimney wasted to such an extent after four years' service that complete renewal was necessary. This section was unlagged and the average gas temperature was about 260° F., and frequent starting up and shutting down was experienced during this period. The problem of corrosion has brought into being numerous methods for its prevention, some of which are :—

(*a*) Lining with acid-resisting cement applied by special gun.
(*b*) Lining with acid-proof bricks set in acid-proof cement.
(*c*) Lining with limpet asbestos and cement applied by spraying.
(*d*) Applying a metal coating of lead or aluminium by oxy-acetylene gun.
(*e*) Fixing asbestos cement sheets with a backing of mastic composition.
(*f*) Coating with paint.
(*g*) Rubber lining.

Method (*a*) has been used and although it has proved satisfactory on some chimneys, speaking generally it has not met with much success. The cement is applied over steel mesh reinforcement secured to the inside of the chimney. In one case a chimney of 9 ft. internal diameter was lined throughout with a 2-in. thickness of cement applied by gun to a backing of steel reinforcement. After six years service it was found that on an average the lining has worn to about a thickness of 1 in. and patches some 2 or 3 yards square were without cement, the reinforcement being exposed. The cement had apparently perished over the period of years. The boiler was of the stoker type with grit arresters fitted between the air preheater and the induced draught fan. The average flue gas temperature at exit was 330° F. and the velocity about 18 ft. per second.

A further example of a 200 ft. × 12 ft. 9 in. chimney where pulverised fuel boilers were installed is of interest. Annual internal painting did not prevent excessive corrosion and a 2-in cement lining was applied. After being in service for four years the upper 30 ft. was attacked by acid to a depth varying from $\frac{3}{4}$ in. to 1 in. and the portions near ground level about $\frac{1}{8}$ in.

Method (*b*) requires special fixings to sectionalise the brickwork, and necessitates a stronger chimney to take the additional loading imposed. For complete protection the lining should be extended the full height of the chimney. It is essential that all joints in the brickwork lining be made impervious to the passage of gas or moisture through them.

Method (*c*) has been tried and proved successful after nearly two years' service on a two-shift station, the station being closed down daily with consequential aggravation of corrosion.

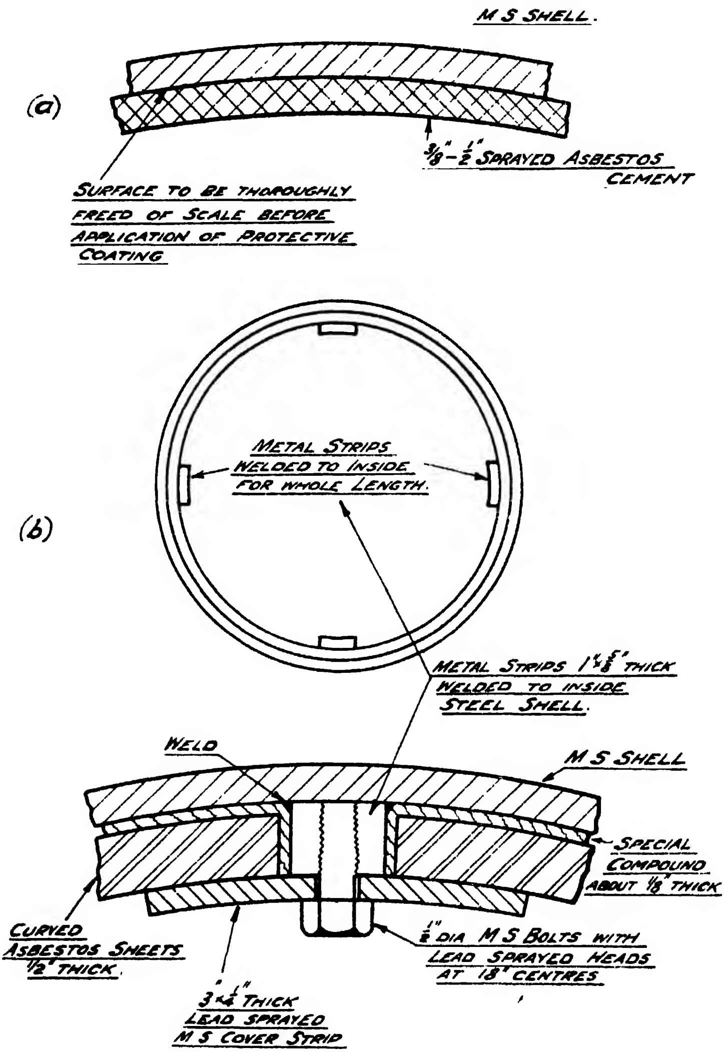


FIG. 172. Linings for Steel Chimneys.

The chimneys are thoroughly cleaned internally and given a coat of special adhesive paint before applying the asbestos-cement (Fig. 172). It is preferable to include reinforcing mesh or spikes

welded to the plates and allow the protective coating to dry out before commissioning the boilers. In this way the coating becomes solidified and good adhesion to the chimney plates is ensured. Experience has proved that it is futile to apply this type of protection once the stack has been subjected to the flue gases.

Method (*d*) is not very popular, particularly lead coatings.

Method (*e*) has been used with success, but requires the chimney to be of all-welded construction. Pre-formed bitumenised asbestos sheets are set in a mastic compound and held with multiple cast-iron clamps which allow the normal flexure to occur without damage. There is little difference in cost between riveted and all-welded construction.

In method (*f*) various paints have been put forward. The ideal paint should be able to withstand the activity of heat, expand and contract along the surface without cracking, peeling or flaking off, and be acid resisting.

Chimneys on boiler plants without air heaters have been painted internally and externally with black graphite paint, and no corrosion troubles have been experienced. A mixture of tar, pitch and natural asphalte was applied internally to four chimneys which have been in service for a number of years and has given fairly satisfactory results.

Whilst "Armco" iron (similar material for rivets) is a good quality material, it has not been able to withstand the attacks of abnormally corrosive flue gases.

The locality in which the station is situated may also play an important part in the choice of chimney construction. For example, in a salt atmosphere the air may attack the materials. The combined action of salt air and water has also been known to destroy stainless steel chimneys. Mild steel chimney plates may be given one coat of boiled oil before despatch to site. In some cases the plates are left self colour after erection and allowed to weather, after which they are thoroughly cleaned and given two coats of paint. The bottom coat could be red lead and the top of aluminium or other paint of the desired colour. Where the chimney is provided with internal protective lining there does not appear to be any necessity for painting the plate lap joints. In any case the joints are riveted and weathered. Trouble is sometimes experienced with vibration due to strong winds, particularly where self-supporting steel chimneys are used. In very squally weather, cold air may be blown down the stack and when this comes into contact with the ascending gases, vibration may ensue. This is likely to take place

where the station is situated in a valley, and especially if the draught is poor. Chimney vibration may also affect the induced draught fans, causing the runners to foul the casings even though expansion pieces are included in the interconnecting ductwork.

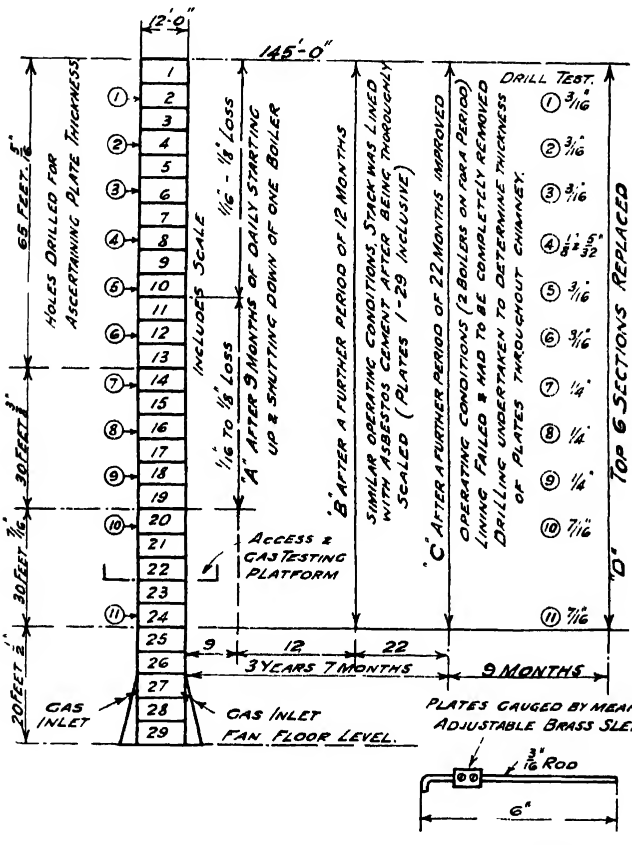


Fig. 173. Steelplate Chimney Investigation Data.

Height of chimney from fan floor level . . . . . . 145 ft.
Diameter of chimney . . . . 12 ,,
Plates—0·6 per cent. copper-bearing mild steel.
Rivets—mild steel.
Two pulverised fuel boilers each 130,000 lb./hr. M.C.R.
Electrostatic precipitator between air heater and I.D. fan.
Plates drilled $\frac{5}{16}$ in. and holes tapped to suit bolts inserted.
Fuel gas temperature- -270–320° F.

Annual inspection of steel chimneys is desirable and the most reliable form of inspection is close visual examination of all the surfaces and in particular the riveted joints and protective coatings.

Any parts in doubt may be hammer tested from the outside and where sections are suspected of excessive wasting the actual thickness of the remaining metal can be determined by drilling,

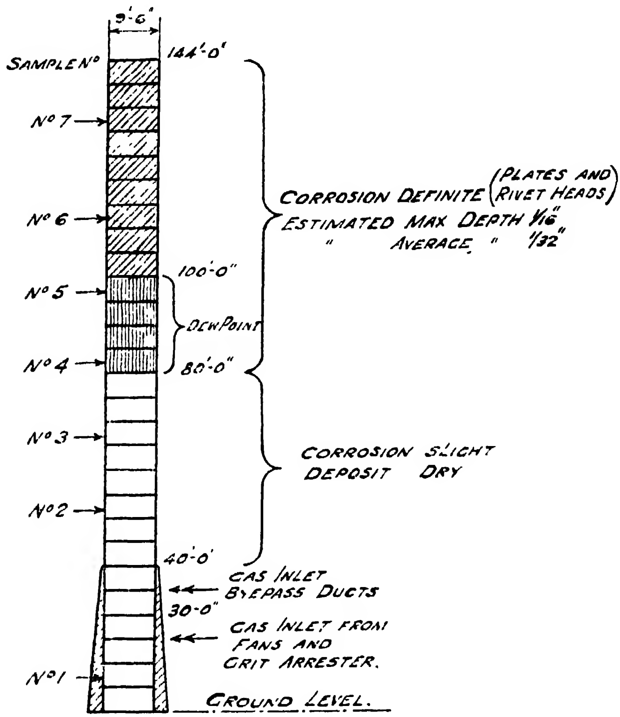


FIG. 174. Steel Plate Chimney Data. (Chain Grate Stoker.)

Notes : No. 1 Deposit --Dry greenish deposit (from brickwork).
,, 2 ,, Dry whitish deposit (corrosion slight).
,, 4 ,, Dry whitish deposit with greenish-brown patches. Corrosion commencing (plates and rivet heads).
,, 5 ,, Deposit definitely moist and greenish colour. Corrosion heavier and scaling commencing.
,, 6 ,, Thicker deposit, dry on surface and moist underneath. Corrosion and scaling heavier still.
,, 7 ,, Similar to No. 6, but drier.

Details of Chimney :

Approximate time in commission to date	**2½ years**
Height from ground level	**144 ft. 0 in.**
Diameter at base	**15 ft. 9 in.**
Diameter above cone	**9 ft. 6 in.**
Plates	**"Armco" Iron**
Rivets	**"Armco" Iron**
Thickness of plates	**⅜ in.**
Approximate temperature of flue gas at chimney base	**350° F.**
Ditto, for last two months	**425° F.**

Fig. 173. Further data relating to steel chimneys are given in Fig. 174.

Some details relating to steel-plate chimneys are appended :—

Boiler capacity	1—187,500 lb. per hour M.C.R.
Type of chimney	Self-supporting steel plate.
Height	170 ft.
Height above grates	154 ft.
Height of lining	45 ft.
Internal diameter—Base	16 ft.
—Top	10 ft.
Thickness of plates	$\frac{7}{16}$ in. (bottom 70 ft.), remainder $\frac{3}{8}$ in.
Foundation bolts	18/2½ in.
Total weight	190 tons (48 tons steel, 142 tons lining).

Lining of the chimney :—

To a height of 13 ft.	14 in. common brickwork
2nd lift	9 in. ,, ,,
3rd lift	4½ in. ,, ,,
Top lift	3in. firebricks.

The second and third lifts faced with 3 in. of firebricks. Common bricks 9 × 4½ × 3 in. best make and the firebricks best Staffordshire quality 9 × 5 × 3 in. thick, curved to suit the radius and grooved at each end. All bricks set in hydraulic lime mortar. The space between the brickwork and the chimney plates filled in with dry rubble.

Working stresses	Single riveted joint, 8,000 lb./sq. in.
	Double ,, ,, 10,000 ,,
Wind pressure	25 lb. per square foot.
Boiler capacity	2—180,000 lb. per hour M.C.R.
Type of chimney	Self-supporting.
Internal diameter	12 ft.

Rise to 160 ft. above roof level and 265 ft. above ground level. They have a coating of bitumen to protect the metal and then lined with a 4½-in. course of " Accrington " acid-resisting bricks erected on cast-iron angle rings attached to the steel shell of the chimney at distances of 5 ft. apart. The pointing of the brickwork is carried out with " Prodorite " acid-resisting cement.

Brick Chimney. These are very expensive to construct, but require little maintenance and may even serve the lives of two boiler plants.

Brick chimneys are lined with acid-resisting firebricks and the additional load imposed on the ground generally necessitates expensive foundations.

An example of brick chimneys is given :—

Boilers installed	8—256,000 lb. per hour M.C.R.
Number of chimneys	4.
Height	250 ft.
Internal diameter—at base . . .	30 ft.
at top . . .	23 ft.

The total weight of a chimney 254 ft. high with a minimum internal diameter of 18 ft. is approximately 2,700 tons, excluding foundations.

A most serious trouble with brick chimneys is a pronounced departure from the perpendicular, referred to as a list, or lean. Such a condition may develop due to unequal settlement of the foundation, or the crushing of mortar in the joints at one side of the lower section of the chimney. Another factor which may cause listing is continuous and quick building which results in the mortar in the joints, particularly those at or near the base, crushing under the weight before it is properly set. This is further aggravated when high winds prevail in one direction during building. Carrying out the work in stages—building, say, 40 to 50 ft. and then leaving for a few weeks until brickwork has had time to consolidate and then continue in similar stages until completion—will obviate this. The use of high-class material and sound workmanship are important factors if a first-class job is to result.

Rapid deterioration of the jointing materials and the brickwork may result if the flue gases are highly charged with acids, sulphur dioxide, etc. The use of acid-proof mortar and bricks overcomes this trouble internally but the upper external sections of the stack are also exposed to attack, since smoke and fumes are blown some considerable distance down the stack from the top. A good internal fire-brick lining serves to protect the ordinary brickwork from excessive heat. Copings at the top should be maintained in good condition otherwise the ingress of rain and snow into the brickwork will have serious effect on the mortar joints. Once cracking has set in it has the tendency to widen and pointing often proves futile so that banding is necessitated. Banding consists of fitting to the defective portions of the stack a number of bands of flat steel or wrought iron, each made up of several lengths which can be bolted together. A brick chimney which has developed a slight list may be straightened if care is taken. One method is removing a course of brickwork from one side of the chimney at the base, inserting supporting plates and wedges as the removal is effected, then taking out the wedges gradually so as to allow the chimney to move back

into the perpendicular and finally filling in the gap with brickwork. Inspection will vary according to circumstances and periodical observations and records assist in this respect.

One chimney, 327 ft. high (Germany), has internal and external sections of brickwork with an intermediate section of concrete.

Concrete Chimney. This type is cheaper than a brick chimney. Some idea of the general construction will be obtained from the following examples :—

Boilers installed	3.
Type of chimney	Shell—reinforced concrete. Inner lining—acid-resisting bricks.
Height	250 ft.
Internal diameter at base . . .	18 ft. 6 in.
External ,, ,, ,, . . .	24 ft. 6 in.
Internal diameter at top . . .	15 ft.
External ,, ,, ,, . . .	17 ft. $2\frac{1}{2}$ in.
Total weight	900 tons.

The foundation for each chimney is of reinforced concrete 6 ft. deep by 44 ft. square, supported on eighty-five reinforced concrete piles, each 14 in. square. The weight of the foundation block is approximately 770 tons, exclusive of the piles. Excluding the effect of wind the load on each pile is about 20 tons. Assuming a wind pressure of 30 lb. per sq. ft. acting on 0·7 of the projected area of the chimney, the pile load would be about 30 tons. The chimneys are in two parts, the shell and the lining (Fig. 175). The shell or outer casing is of concrete tapering in thickness from $11\frac{1}{2}$ in. at the base to $5\frac{1}{2}$ in. at the cap, reinforced with $\frac{3}{8}$ in. diameter horizontal rings in two diameters, the outer at 5 in. centres and the inner at 8 in. centres vertically, and verticals of $\frac{1}{2}$ in. diameter rods at 7 in. centres. The lining is of acid-resisting brick set in acid-resisting cement mortar $4\frac{1}{2}$ in. thick throughout, with the exception at flue inlets and the base, where the brickwork is 9 in. thick.

The linings are in lengths of 40 ft. or so, each being supported on a concrete bracket the full circumference of the shell. The bottom of one length of lining is flashed to the top of the lower length with lead flashing. The space between the outer shell and brick lining enables ventilation to be maintained throughout the height by including holes in the supporting brackets at each length. Ventilation holes are also provided in the shell from which the heated air escapes and so maintains a continuous circulation of cool air. The shell is therefore kept at or near atmospheric temperature and much below that of the brick lining. Another interesting feature of these chimneys is the method of construction adopted. The shape of the

shell at the top is circular, but at the base it consists of eight circular arcs joined by eight straight sides. The radius of the arcs at the bottom is the same as the radius at the top. If the chimney was

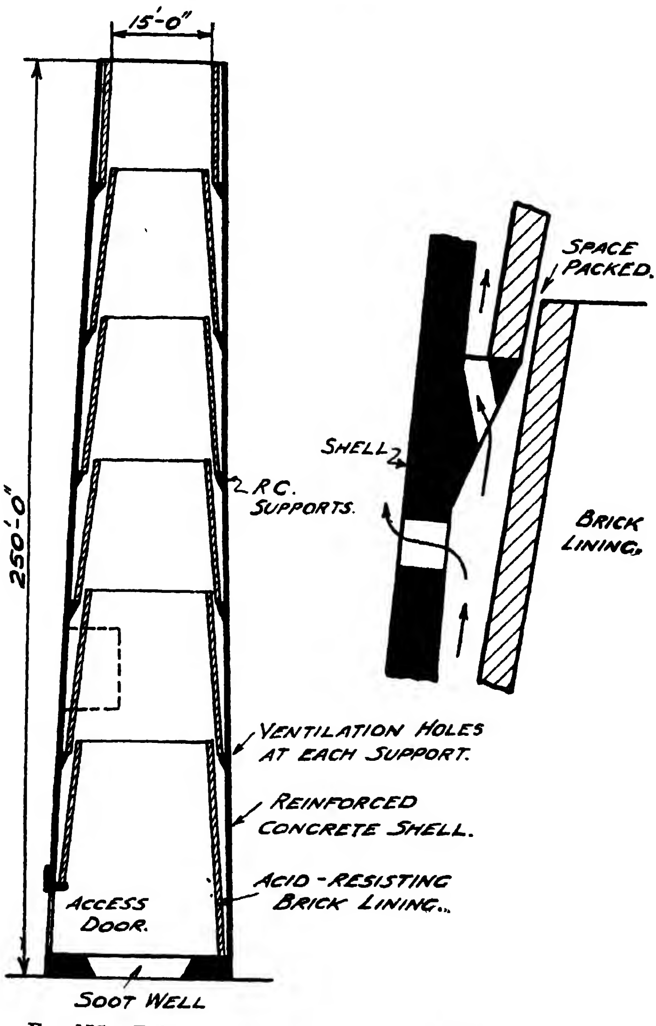


FIG. 175. Reinforced Concrete Chimney Details. (Tileman.)

circular from top to bottom the diameter would vary throughout the entire height and special shuttering would be necessary for each section poured. The circumference at the top is divided into eight equal arcs, and these form the circular arcs at the bottom. In

between these arcs straight widths of shuttering are used. When the bottom length of shell is poured the only alteration to the shuttering to make it suitable for the next lift is to reduce slightly the width of the straight pieces. The brick lining follows the shape of the outer shell, varying in distance from it from 4 in. at the base to 14 in. at the top of each section of lining. The base of the chimney is well-shaped to hold flue dust, grit, etc., a door being included at ground level. Climbing irons are provided on the outside to the full height of the chimney. Reinforced concrete chimneys, like steel chimneys, have been anchored on steel supporting girders, and some details of such chimneys are given. In one case the chimneys were placed on massive steel towers (encased in brickwork) at a height of about 18 ft. above ground level. The mix for the chimneys was 1 part of Ferrocrete cement to 1½ of sand and 3 of broken stone. The base is 28 ft. 2 in. internal diameter with a thickness of 10 in., and the top is 22 ft. diameter and 6 in. thick. There are forty-eight 6 × 3 in. vertical flutings on the outer face of each chimney. The tops of the chimneys are about 337 ft. above ground level. The reinforcement consists of a helical system of ½ in. diameter bars at 6 in. centres on each side of the shell. The angle of pitch is 60° to the horizontal, and the bars on the outside run in the opposite direction to those on the inside face. Vertical bars ¾ in. diameter at 6 in. centres forming a diamond-shaped interlacing are also provided, together with the horizontal bars at 5 in. centres. The chimneys are anchored by 1⅛ in. diameter bars extending to the underside of 7 ft. deep double-supporting girders which are secured by nuts. The space between the supporting girders is filled solid with concrete. The rate of building was three lifts of 4 ft. each per week. The reinforced concrete work was tamped, rodded and vibrated. Gas-washing plant is installed, and it was considered unnecessary to include acid-resisting lining. The chimneys each weigh about 545 tons.

It is possible to erect very large chimneys on small foundations providing the site conditions permit of this being done. As an example, two chimneys were built on rock foundation and the excavation necessary did not exceed 18 in.

The particulars of these chimneys are :—

Height	335 ft.
Internal diameter at base . .	28 ft.
,, ,, at top . .	25 ft.
Thickness of shell . . .	11 in. tapering to 6 in. at top.
Total weight	4,400 tons (each).

The chimneys are of reinforced concrete and have a special brick lining.

Another example of reinforced-concrete construction is given :—

Height	300 ft. (above ground level).
Internal diameter at base .	21 ft. 6 in.
,, ,, at top .	17 ft. 9 in.

Unlined, as gas-washing plant is installed.

The wall thickness above the bottom plinth is 12 in., tapering to 7½ in. at the top.

Total weight . . . . 800 tons.

A reinforced concrete chimney in which the author suggested that the lower 120 ft. be utilised for administrative offices is shown in Fig. 176.

The power station is situated about one mile to the north-west of the city centre, being bounded on the east and west by rising ground on which considerable residential property is built. It lies in a valley and hills rise sharply on either side to a height of from 100 to 150 ft. Further ranges of hills more remote from the station rise to heights of from 500 to 900 ft. above the station site level, and in these circumstances it seemed likely that the local health authorities would require a chimney of sufficient height to prevent an unduly high concentration of sulphurous gases anywhere in the city. Having regard to the diameter and height necessary, the fact that the sub-soil of the site is not too good, and the nearness of the chimney to the existing cooling water culvert, a reinforced-concrete chimney was considered to be better than a brick chimney, since the load imposed on the foundations is considerably lower. Experience has shown that the dependability of well-designed and constructed reinforced-concrete chimneys is now beyond question, and that the possibility of failure is at least as remote as with brick chimneys, if not more so. The boiler mechanical draught plant is placed on an upper floor of the boiler-house, the outlets of the induced-draught fans passing through the roof. This lay-out affords a direct inlet for the flue gases to the chimney at boiler-house roof level, or about 100 ft. above ground level. Therefore, it did not appear necessary to carry the chimney down to ground level unless the lower 100 ft. could be put to good use. The existing administrative offices at the station were inadequate and, in view of the proposed boiler-house extensions, the position was not altogether satisfactory. The author decided that there was much in favour of incorporating the offices at the base of the chimney, for not only did this position utilise valuable space, but also the offices are centrally disposed and afford direct access to the boiler and turbine

houses without leaving the buildings. Moreover, the height of the chimney shaft is then only 250 ft. above the flue-gas inlet chamber. Following the recommendations of the former Electricity Com-

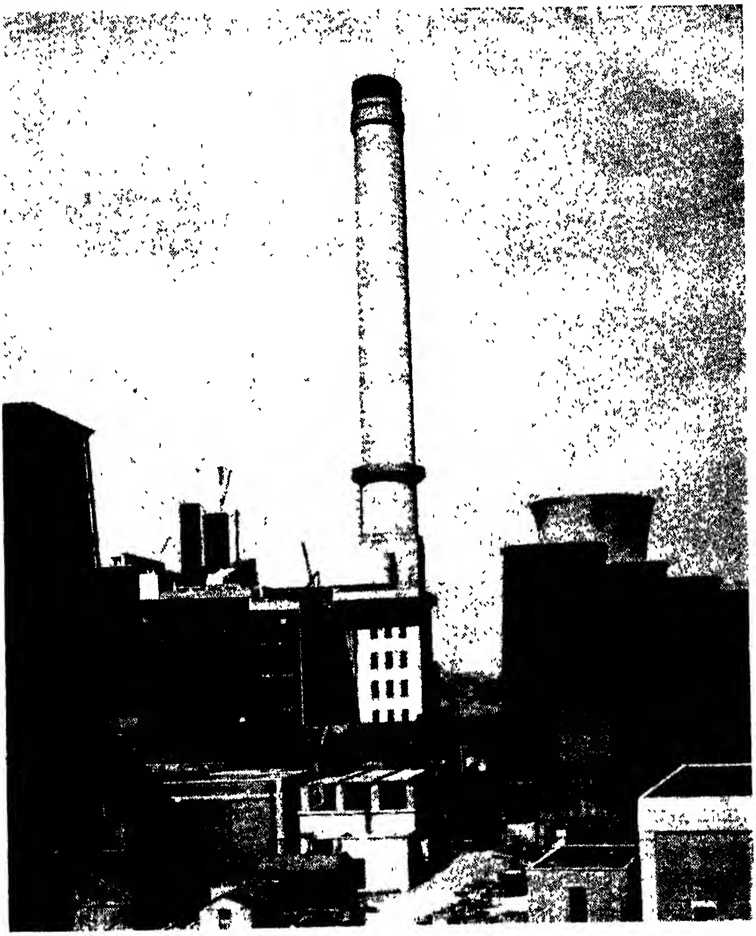


FIG. 176. Reinforced Concrete Chimney, 351 ft. high, 22 ft. internal diameter. (Tileman.)

missioners, the chimney should be 250 ft. high, but, in view of the rising land on the east and west sides of the power station, it was decided to increase the height to 350 ft. above ground level, thereby allowing an additional 100 ft.

Loads and Working Stresses

Loads

Self weight of concrete	144 lb. per ft.^{3}
„ „ „ brickwork	128 „ „ „
Super load on tower floors	112 „ „ ft.^{2}
„ „ „ platform slabs	112 „ „ „
„ „ „ „ „	50 „ „ „
Wind load on projected area of circular shaft	20 „ „ „
„ „ „ octagon	25 „ „ „
„ „ „ tower	15 „ „ „

Working Stresses

Concrete. As Table 2, p. 22, D.S.I.R. Code (1933). Allowable increase in stresses under maximum wind load, 25 per cent.

Steel. As Column 1, Table 4, p. 25, D.S.I.R. Code (1933). Allowable increase in stresses under maximum wind load, 25 per cent.

Modular ratio (all mixes), 15.

Maximum temperature of flue-gases, 350° F.

Since the building of this chimney, B.S.S. 449 (1948) has been issued and should be referred to.

Choice of Pile. The use of cast *in situ* piles was decided upon chiefly owing to the nearness of existing buildings, circulating water culverts and the ability of the piles to carry high loads. Site restrictions for casting, handling, and driving meant that pre-cast piles could not be considered. The question of vibration, however, largely influenced the choice of bored *in situ* piles. The specification called for piles of not less than 17 in. diameter, to be carried down to such a depth that a safe load of 50 tons per pile would be guaranteed. A number of piles had to be tested with a dead load of one and a half times the safe guaranteed load.

Foundation Raft. The depth of the foundation raft (Fig. 177) was chosen to avoid undue loading on the adjacent cooling water culvert. The excavations were carried down to about 3 in. below the bottom of the raft and, after the pile positions were set, this area was covered with mass concrete to enable excavation spoil from the piles to be easily cleared away. The raft was concreted in six portions over a period of eight days, the day-to-day joints being made by stepping the edges adjacent to the next section. Thus each section of the foundation was concreted to the full height in one operation.

Office Block Tower. The shell, which is a hollow square, 32 ft. by 32 ft., with 13 in. walls thickened to 15 in. at the corners, was constructed with sliding shutters consisting of a single belt 4 ft. high made with $1\frac{1}{2}$ in. of planed sheeting supported by 9 in. by 3 in.

ribs, diagonally braced between the jacks. The sliding shutters were raised by means of twenty-four jacks operating on 1 in. diameter mild steel rods. The placing of the concrete proceeded continuously day and night at an average rise of about 10 ft. per day.

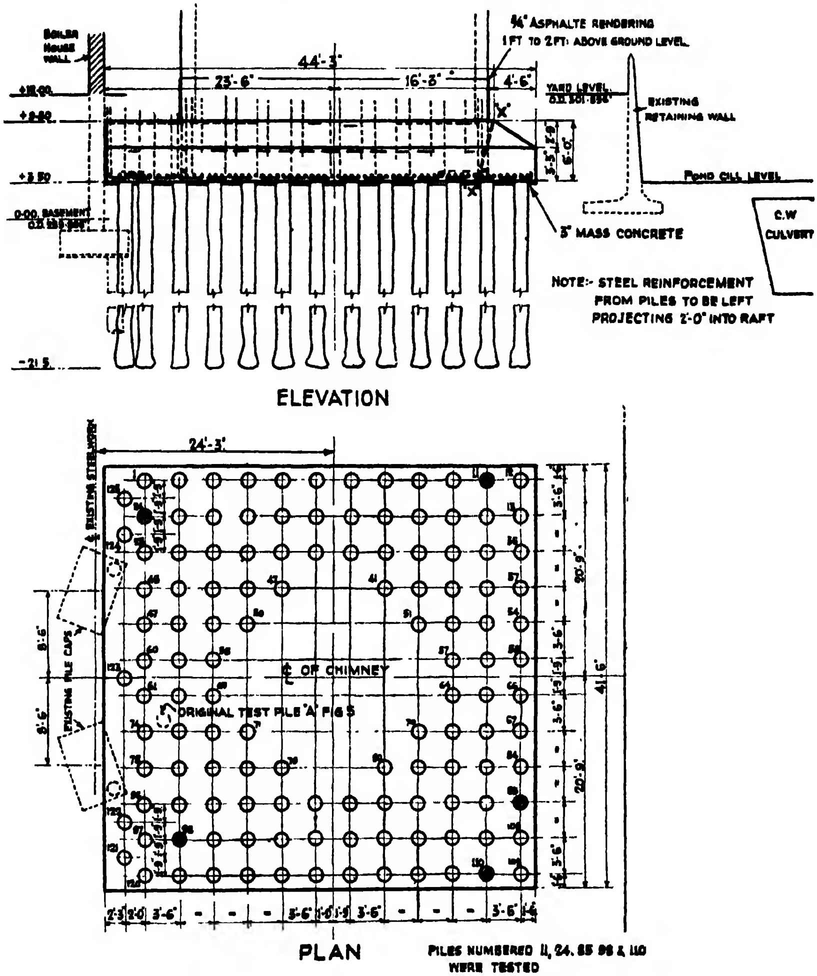
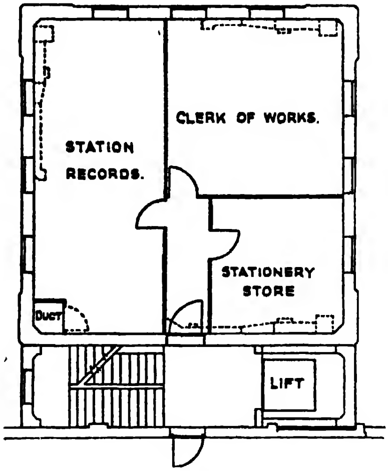


FIG. 177. Piling Plan.

Therefore, with shuttering 4 ft. high, any part of the concrete wall was supported for a period of nine hours, which was sufficient for the concrete to develop its initial set. The floor over the sixth storey was concreted, except in the centre, and the lower floors were put in later. The " slide " method can be used only when the



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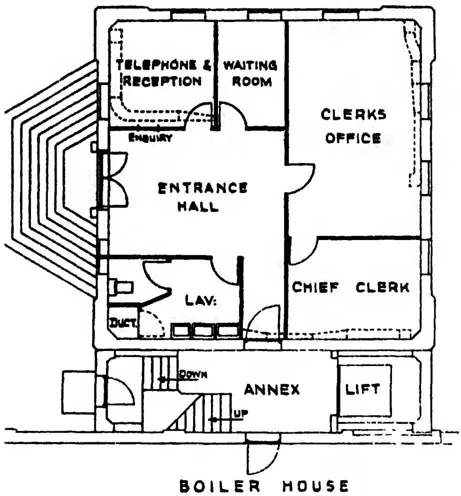

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walls are parallel throughout. As a protective measure against attack by acid and damp, lower portions of the tower sides were given a $\frac{3}{4}$ in. covering of asphalt. Fig. 178 shows the general layout of the offices.

Flue-Gas Inlet Chamber. The arrangement adopted is shown in Fig. 179 and has two flues on the boiler-house side and one in each of the sides which adjoin the boiler-house. The ducts enter the inlet chamber independently and the loading is symmetrical. The inlet chamber is constructed as a rectangle with two corners

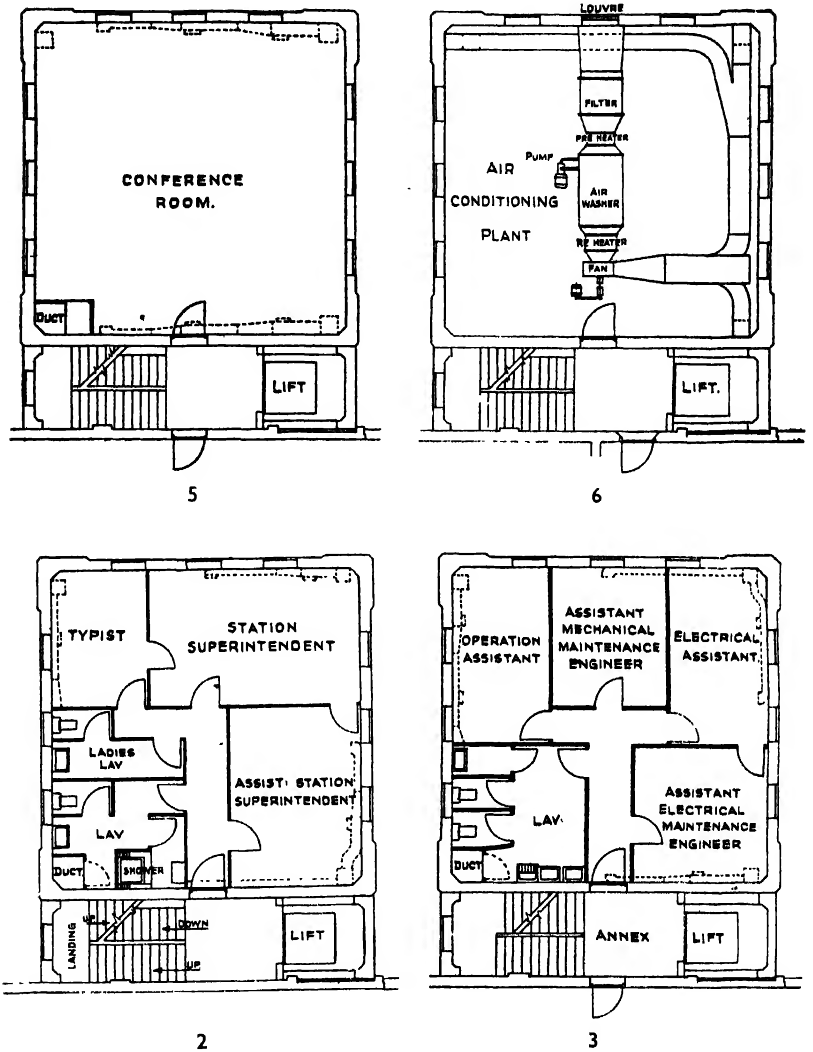


Fig. 178. Office Layout.

cut off on the side away from the boiler-house and the internal face is made circular to line with the chimney shaft. As two of the gas ducts enter the chamber directly opposite each other, a mid-feather wall is included which extends about 8 ft. above the top of the ducts. A brick-lined reinforced-concrete flue dust hopper, the sides of which have a slope of 55° to the horizontal, is provided immediately

below the inlet. The hopper outlet is connected to the flue-dust extraction plant. Doors are included on each side of the mid-feather wall to afford access to both sides of the chamber.

Chimney Shaft. The shell thickness ranges from 9 in. at the bottom to 6 in. at the top. Calculations show that no tension occurs on the section at the bottom (section 2, Fig. 180) or on section 1. Vertical and horizontal steel is provided to resist temperature stresses. The maximum stresses due to temperature are 8,850 lb./sq. in. and 8,000 lb./sq. in. in the horizontal and vertical reinforcements, on the assumption that the flue-gases are at 350° F. and the outer air at 50° F. The wind pressure blowing on one side of the shaft tends to distort the section from the circular to an oval shape, and here again the reinforcing steel (horizontal) is mostly for temperature stresses. Under the worst conditions, with an unlined shaft, no tension occurs. The temperature drop through the chimney with flue-gases at 350° F. and air at 50° F. is approximately as follows :—

(1) At a section where the shell thickness is 9 in., the brick lining is $4\frac{1}{2}$ in., and there is an air-space of 6 in., the approximate drops through the various parts will be :—

	°F.
(*a*) Brick lining	50
(*b*) Ventilated air-space	134
(*c*) Concrete shell	80
(*d*) Outside drop	36
Total	300

(2) At a section where the shell thickness is 6 in., the brick lining $4\frac{1}{2}$ in., and the air-space 6 in., the drops will be :—

	°F.
(*a*) Brick lining	55
(*b*) Ventilated air-space	147
(*c*) Concrete shell	59
(*d*) Outside drop	39
Total	300

There are three courses of material, in which respectively the thicknesses are d_1, d_2 and d_3 ; the conductivities are K_1, K_2 and K_3, and the temperatures of the faces are t_2, t_3 and t_4, with t_1 the hot face temperature. Then, for a single course of material, the normal conduction formula is $Q = \dfrac{KA\ (t_1 - t_2)}{d}$.

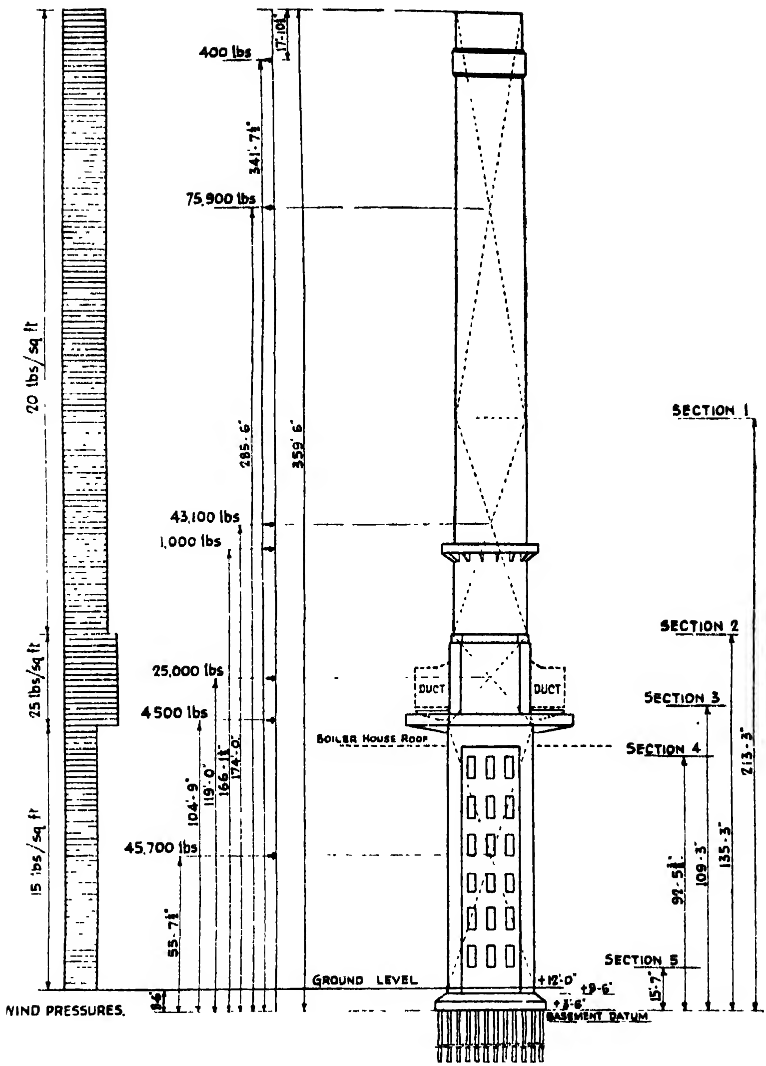


Fig. 180. Wind Loading Diagram.

where Q = heat flow B.Th.U./sq. ft. hr.

K = conductivity.

t_1 = the temperature of the hot face, °F.

t_2 = the temperature of the cold face, °F.

Assuming, Q, the heat flow, is the same for all sections, therefore

$$Q = \frac{K_1 (t_1 - t_2)}{d_1} = \frac{K_2 (t_2 - t_3)}{d_2} = \frac{K_3 (t_3 - t_4)}{d_3}$$

Hence, $\frac{Qd_1}{K_1} = (t_1 - t_2)$, $\frac{Qd_2}{K_2} = (t_2 - t_3)$, and $\frac{Qd_3}{K_3} = (t_3 - t_4)$.

Adding the expressions for each of the three sections, we now have

$$\frac{Qd_1}{K_1} + \frac{Qd_2}{K_2} + \frac{Qd_3}{K_3} = (t_1 - t_2) + (t_2 - t_0) + (t_3 - t_4)$$

or

$$Q\left(\frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3}\right) = t_1 - t_4$$

hence

$$Q = \frac{t_1 - t_4}{\frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3}}$$

and for any number of sections (n)

$$Q = \frac{t_1 - t_n}{\frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3} \dots \frac{d_n}{K_n}}$$

where t_n is the outer face temperature.

K for concrete	1·0	Relative conductivities.
,, ,, brick lining	0·8	
,, ,, ventilated air space	0·4	

The more usual shuttering and lift method was adopted, and consisted of four belts of circular shutters, each about 3 ft. 3 in. (with no overlap of the shutters on the previous lift of concrete, each shutter being stood on top of the previous one). Owing to the taper of the shaft, it was necessary to make some adjustment in the diameter of the shuttering, and this was arranged by leaving spaces between the shutters at the bottom of the shaft and later closing the spaces by steel plates bent to the radius of the shaft. As the diameter of the shaft decreased, the spaces between the shutters were decreased accordingly. The shaft has a 4½ in. brick lining, separated by an air-space from the outer shell and extending from the hopper to the top of the shaft. This lining was built in separate sections, each section being supported on a concrete shelf or ring round the inside of the chimney-shell. The distance between each shelf is 29 ft. 3 in., or nine lifts of the shutters. The hopper has a 4½-in. brick lining, and the flue-gas inlet chamber a 9-in. brick lining. The bricklaying was carried up following the shell, the workmen being protected by an overhead scaffold. In order to obtain

samples of the chimney flue-gases, in accordance with B.S.S. 893—1940, sampling points are located in the chimney shaft. The internal diameter at the point of entry of the ducting is 23 ft.; therefore the minimum height at which the gas sampling points should be placed above the point of entry is 28 ft. The position chosen is about 44 ft. above this point, where eight holes, equally spaced round the periphery, are provided for taking 10 in. internal diameter cast-iron pipe inserts. Each pipe has a flange fitted at the outside of the chimney.

To facilitate inspection and maintenance, step irons at 13 in. centres are provided from the flue-gas testing platform to the top of the shaft, there being three steps per shutter lift. Local steeple-jacks were consulted and were satisfied with the use of bronze steps, $\frac{3}{4}$ in. diameter by 8 in. by $3\frac{1}{2}$ in. by $3\frac{1}{2}$ in. fixing; but they suggested that it would be helpful if four bands of steps were placed round the top of the chimney. The first band is placed 1 ft. below the top, the steps being spaced 18 in. apart; the next row is 4 ft. 4 in. below this: and the third and fourth rows are placed at similar distances. The lower two rows were designed to carry 5 cwt. per step.

The top of the chimney is protected by means of a cast-iron cap, which consists of thirty-two equal sections. Each section is butt-jointed, with a $\frac{3}{4}$ in. gap between the sections filled with bitumen. The total weight of the capping is 2·3 tons.

Protective Finish. The protection of the outside surface of the shaft and tower against the action of sulphurous flue gases which are frequently blown down was duly considered. It was found that on very few chimneys had a paint finish been applied, and only those which had been given a black bitumastic finish had proved satisfactory. On many concrete chimneys a colourless hardener, which has a good appearance, had been used and found satisfactory. A very dilute solution of silicate of soda was applied to the concrete surface when it was clean and dry. The calcium silicate and silica soak into the pores of the concrete to an appreciable depth ($\frac{1}{4}$ to $\frac{1}{2}$ in.), and on drying leave the pores almost completely filled. To ensure a good finish, three coats of solution were applied. The treatment imparts a glaze to the concrete surface and renders it more or less impervious to moisture and polluting gases in the atmosphere. The solution used contained about 30 per cent. silica and 9 per cent. soda diluted with three to four times its own volume of water. As a further protection against acid attack, the tops of the lower flat portions of the inlet chamber, etc., were given a coating of black bitumastic paint.

Office Block Annexe. This structure, which serves as a disconnecting corridor between the chimney-tower and the boiler-house, is 32 ft. long, 7¾ ft. wide, and 94 ft. high from the foundations to the roof over the lift-motor room. The walls, which are 13 in. thick, seat 18 in. deep by 9 in. wide reinforced-concrete beams for supporting the stairs and landings. A lift-well is formed in this structure with the motor-room overhead. Expansion joints are provided between the tower portion and the annexe walls, and also between it and the boiler-house, so as to allow for any movement of the chimney. The cubic capacity of the six office-block floors is about 70,500 ft^3. The basement below the first floor serves as a marshalling chamber for cables and pipes ; and a duct extends from it to the top floor.

Lightning Protection. The orthodox lightning conductor is not suitable for a power station chimney, owing to corrosion and to difficulty, and the costly nature, of repairs and replacements that may be found necessary. An exceptionally heavy main conductor system with air terminals made in acid-resisting unpolished bronze was installed. The cast finish is extremely hard and is not so liable to corrosion as would be the case after turning. The terminals, fixing brackets, tape couplings and junction boxes were tinned by hot process to afford further protection against acid attack. The high-conductivity copper tape in the upper 40 ft. of the chimney is seamless lead-covered, with the ends tinned. The thirty-two sections of the cast-iron chimney cap are bonded together by lead-covered copper tapes to make them electrically continuous. The six air terminals are interconnected at about 4 ft. from the chimney top by a lead-covered coronal band, the joint between which and the copper tapes from the finials is made by tinned junction boxes. Two down tapes are fitted, and at the flue-gas duct platform a copper interlinking tape is provided, from which copper bonds are made to the conductor. The ducting is earthed by way of its association with the remainder of the building steelwork. The down tapes continue from this platform-level to test-clamps placed at a convenient height above ground level to facilitate the testing of the separate earth termination as required. For each down tape there are three driven earth electrodes, 16 ft. long, which it is estimated will result in reaching the water level. The two groups of earth electrodes are interconnected by a continuous base tape running below ground level (also see Chapter XVIII, Vol. 2).

Schedule of Technical Data. The following data relate to the principal sections of work :—

Item	Chimney Shaft	Piling	Other Work
Concrete mix	1 : 1½ : 3	1 : 2 : 4	Pile 1 : 2 : 4 Caps 1 : 1½ : 3
Grade of concrete (code of practice)	High	Ordinary	High
Safe stress in concrete, lb./sq. in.			
Bending	1,100	750	950
Direct	880	600	760
Safe stress in steel, lb./sq. in.			
Bending	18,000	18,000	18,000
Direct	13,500	13,500	13,500
Modular ratio	12	18	14
Thickness of shaft, in.			
Top	6	—	—
Bottom	9	—	—
Tower walls	(1 : 1½ : 3) mix	—	13 in. thick
Foundation raft . . . ft.	—	—	41·5 × 41·5 × 6
Weight of chimney shaft and tower . tons	2,700	—	Annex 220
,, ,, ,, ,, lining . . ,,	511	—	—
,, ,, foundation raft . . ,,	—	—	665
,, ,, chimney-shaft reinforcement . ,,	32	13	Office block tower 56 tons Flue sections 29 ,, Foundation 11 ,,
Number of piles	—	Chimney 120 Annex 5	
Maximum load on each pile . . . tons	—	50	—
Pile-length . . . ft.	—	25 and 26	—
,, -diameter . . . in.	—	17	—
,, -base diameter . . . in.	—	36	—
Vertical reinforcements . . ,,	$\frac{5}{8}$ dia. B. $\frac{7}{16}$,, T.	6 bars $\frac{7}{8}$ dia.	—
Horizontal reinforcements . . ,,	$\frac{1}{2}$,, B. $\frac{3}{8}$,, T.	$\frac{1}{4}$ dia. 5 pitch	—
Total weight, excluding annex . tons	—	Wound spirally	4,122

Costs. Although the costs would not apply under present-day conditions, they are given for guidance, especially in respect of the different sections of work. This chimney was constructed during the period 1944–46.

	£
Chimney and tower	31,255
Piling	3,474
Annex	2,555
Lightning conductor	500
Inlet chamber flue gas frames	200
Special silicate of soda finish, etc.	1,000
Special insurance	41
Air conditioning plant for office block	1,700
Lift and builder's work	1,200
Hot and cold water supplies, lighting, office partitions, flooring, decoration, handrail, etc.	7,130
Increase in cost of materials and labour on chimney and annex (Essential Works Order and Uniformity Agreement)	3,000
Total	£52,055

Further details will be found in the paper presented by the author to the Institution of Civil Engineers (*J. I. C. E.*, No. 6, April, 1948).

The Monnoyer system of chimney construction is sometimes used where local authorities raise no objections. Such chimneys are built of specially-shaped precast reinforced concrete blocks about 2 ft. 6 in. by 11¾ in. by 4½ in., which are keyed horizontally and vertically by reinforcing bars grouted in slots in the outer edges of the slabs.

When gas-washing plants are installed it appears justifiable to omit acid-resisting brick linings on reinforced concrete chimneys, since very little sulphur and fly-ash would pass to the chimneys. Fly-ash contains a fairly large proportion of Glauber's salt and this may be deposited on the top of the chimney. Dissolved in rain-water it runs down the stack and finds its way into the pores of the concrete and on crystallising its disruptive force splits the concrete. To reduce deterioration from this cause the outside surface of the chimney near the top (40 to 50 ft. down) may be treated with acid-resisting paint. The flues can enter a very large receiver or downcast chamber to rid the gases of excessive grit before passing to the chimney.

Aluminium Chimney. Self-supporting tapered aluminium chimneys have also been developed and incorporate a special type of asbestos insulation lining which reduces the temperature near the aluminium to working limits. Vents are provided at various levels so that cold air can pass between the lining and the aluminium for cooling purposes. The chimney proper is built from fluted aluminium extrusions which are riveted together on the inside and kept in shape by horizontal rings. The latter are also used to support the lining, which is in panels to facilitate handling. The time required to erect a 300 ft. chimney is some three months after completion of foundation work. With aluminium only 3 per cent. of its carrying capacity is used to hold itself up, whereas in concrete this amount is 33 per cent. A 300 ft. chimney with its insulation is not more than 100 tons. The aluminium alloy used is resistant to most flue gases and industrial atmosphere. It weathers fairly quickly, the fluted appearance is pleasing and maintenance charges are but small. From a review of existing plants it would appear that gas velocities of from 15 to 35 ft. per second are common. Assume 6 boilers (each 180,000 lb. per hour.) are normally steaming out of 8 boilers installed with a gas outlet temperature of 300° F. and 11 per cent. CO_2. 1·2 lb. coal per 10 lb. of steam, approximate flue gas per lb. of coal = 15 lb. Volume of gas per lb. of coal at 300° F. = 290 ft.^{3}

$$\text{Volume of flue gas} = \frac{6 \,.\, 180{,}000 \,.\, 1{\cdot}2 \,.\, 290}{3{,}600}$$

$$= 10{,}400 \text{ ft.}^3 \text{ per second.}$$

with a 22 ft. internal diameter chimney;

$$\text{velocity} = \frac{10{,}400}{0{\cdot}7854 \,.\, 22^2}$$

$$= 27{\cdot}4 \text{ ft. per second.}$$

Alternatively, assuming 16,140 ft.^{3} per 100 lb of coal (including vapour) and 12·5 per cent. CO_2, then 16,140 $\left(\frac{460 + 300}{460 + 32}\right) =$ 25,000 ft.^{3} per 100 lb. of coal. Volume of gas per lb. of coal = 250 ft.^{3}

$$\therefore \quad \frac{6 \,.\, 1{\cdot}2 \,.\, 180{,}000 \,.\, 250}{3{,}600}$$

$$= 9{,}000 \text{ ft.}^3 \text{ per second.}$$

$$\text{Velocity} = 23{\cdot}6 \text{ ft. per second.}$$

The volume of gas is proportional to its absolute temperature. Air entering at a temperature of 80° F. has an absolute temperature of 540° F. and gases leaving the air heater to the chimney at 300° F. have an absolute temperature of 760° F. Dividing 760 by 540 we get 1·4, *i.e.*, the volume of the gases entering the chimney are 1·4 times the volume of air delivered to the boiler.

Chimney Emission. There is but little published information on this subject, and the author carried out investigations which were primarily concerned with the measurement of the spread of chimney pollution. The high sulphur and ash-contents of the coal burned, together with the methods of firing, all contribute to an increase in the pollution of the surrounding atmosphere by chimney emission. Atmospheric pollution from steam power plants is created by : Grit emission and smoke, including tarry matter ; gaseous oxidation products of the sulphur compounds present in the fuel burned, together with other gaseous waste products. To assess the pollution from these causes it is necessary to measure the amounts which reach the ground at varying distances from the points of emission. For the purpose of these investigations it was decided to measure (*a*) the amount of grit deposition, and (*b*) the amount of sulphur-dioxide present in the air at a number of selected sites situated at varying distances from the power station. To estimate the amount of insoluble and soluble material falling on unit area, a

deposit gauge similar to that developed by the Atmospheric Pollution Research Committee of the D.S.I.R. was used (see paper by T. H. Carr and W. D. Jarvis, *J. I. C. E.*, No. 6, April, 1949). The deposit, together with any rainwater retained by the funnel and bottle receiver, was collected each month and analysed to determine the amount of each of the following constituents : Insoluble solid matter : ash-content and loss on ignition. Soluble solid matter : chloride and sulphate content. Water. The area presented by the funnel having been determined, the results were expressed in tons per square mile per month. To measure the distribution of pollution in calm weather, the Petri-dish test was employed. The estimation of the amount of sulphur-dioxide in air at ground level was made by the lead-peroxide method.

In collaboration with the Superintendent of Observations, Atmospheric Pollution Research (D.S.I.R.), it was decided to distribute twelve observation stations within an area having one mile radius from the chimneys at the power station. Wherever possible, use was made of the department's substations, which have flat roofs about 15 ft. from ground level ; this height served to restrict unnecessary interference. A deposit gauge and a lead-peroxide apparatus were installed at each station, and, in addition, the monthly results of an analyses from two deposit gauges operated by the local authority's health department were available. Winter and summer periods of observation were made. There are several factors which vary in amount and which themselves react to influence pollution concentration. These are : (1) Amount of coal burned ; (2) amount of ash in coal ; (3) amount of combustible sulphur in the coal ; (4) rainfall ; (5) direction and velocity of wind ; (6) emission from chimneys of other industrial plants in the area under review ; (7) domestic pollution in the area ; and (8) seasonal variation as provided by winter and summer periods.

For the purpose of determining the mean monthly ash distribution, eliminating as far as possible the effect of variations in wind force and direction, use was made of an area grid. This was constructed by drawing on tracing linen four circles which have a radius, respectively, of a quarter, half, one and two miles (of the same scale as the site map). These areas (0·196, 0·785, 3·142 and 12·570 square miles respectively) were each divided into six segments, and the centre of gravity of each segment was determined and marked. The grid was superimposed on the ash distribution map, and from the values so obtained the mean ash deposition, in tons, for each area was derived. Thus, for each month, four mean con-

centration values were produced, from which a curve was drawn (having area in square miles as co-ordinates, and ash in tons as abscissæ) showing the spread of ash distribution in terms of area. Considerable variation was shown from month to month. For example, a particularly high concentration of ash deposition was recorded when a very strong wind force obtained. On the other hand, very low values were recorded during heavy periods of snowfall, and it is probable that some of the deposited material was lost by the filling up of the funnels with snow.

Contour maps were constructed from the individual determinations of SO_3 absorbed by the lead-peroxide apparatus at each observation station, and the mean distribution of SO_3 on the areas under review relative to the chimneys represented on the area grid was estimated. SO_3 distribution curves were drawn, from which were read off the areas on which 10 per cent. and 20 per cent. of the combustible sulphur in the coal burned each month was absorbed. The conclusions reached in this particular investigation are given in the paper already referred to and were contrary to the findings of some other investigators.

One authority has suggested that the smoke concentration at the ground varies almost inversely as the square of the chimney height ; beyond fifty chimney lengths the concentration varies inversely as the square of the distance. To obtain the normal full load chimney discharge velocity of 60 ft. per sec. one American station near a large housing estate has a nozzle fitted on the top of each chimney which is 300 ft. high. Inside this nozzle and concentric with it, a second nozzle with damper is placed. With this damper closed, the gas passes through the restricted annular area, thereby raising the exit velocity to 120 ft. per sec. This velocity is deemed necessary under critical wind conditions to keep the chimney plume well clear of the ground. To maintain this high velocity at less than full load a by-pass is included between the F.D. fans and the base of the chimney. Pressurised boilers are installed.

To further control the chimney emission the operators have equipment which includes a television viewing monitor to show condition of the chimneys ; a smoke indicator which operates on the light absorption principle ; an atmospheric air analyser located in the direction of the housing estate to measure the SO_2 gas and transmit an indication and alarm, and a wind velocity and direction unit located on the top of a nearby gas holder to indicate wind conditions.

PULVERISED FUEL PLANTS

In this method of firing the coal is reduced to a fine powder and projected into the combustion chamber by means of a current of hot air. A further volume of preheated air to make up the necessary amount for combustion is blown in separately, and the resulting turbulence in a high temperature combustion chamber facilitates thorough combustion. The hot air referred to is termed primary air, whilst the preheated air for combustion is known as secondary air. The general application will be understood on referring to the accompanying illustrations.

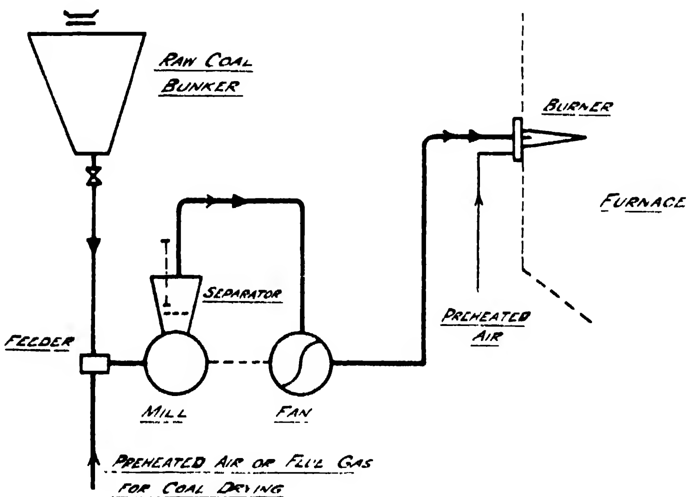


FIG. 181. Pulverised Fuel Unit System.

The boiler unit is similar in most respects excepting that the stoker is replaced by burners and the inclusion of a screen of water tubes at the bottom of the combustion chamber for cooling the ash. Explosion doors are provided at the top of the boiler to relieve any excessive pressures. The two methods in general use are the Unit and Central systems and these will be briefly outlined.

Unit System. The Unit or Direct system, Figs. 181 and 182, consists of a feeder, pulveriser, separator, fan, coal and air pipes and burners. The pulveriser, together with feeder, separator and fan, may be arranged to form a complete unit or mill, the number of units required depending on the capacity of the boiler. The raw coal falls by gravity from an overhead bunker into a receiving hopper and then on to the feeder which regulates the flow to the pulveriser. In

some cases automatic weighing machines are installed between the overhead bunkers and the feeders. After milling, the coal dust or fuel is extracted from the pulveriser *viâ* a separator by an exhauster fan, which discharges it to the burners with either hot air or flue gas. In one plant the primary air fans or exhausters are installed

FIG. 182. Pulverised Fuel Boilers at Dunston "B" Power Station. (Clarke, Chapman & Co. Ltd.)

on the clean air side of the pulverising circuit, in which case the mills are always operating under pressure. With this arrangement the fans are not subject to the abrasive action of the fuel and blade erosion is reduced. The raw coal is dried before it enters the pulveriser, and the hot air together with the fuel is delivered by the fan to the burner. Circular section cast-iron pipes are used for

conveying the mixture of fuel and air to the burners. These pipes are lagged and one spigot and socket-joint may be included in each feed line to allow for expansion.

The milling plant forms the largest item of auxiliary equipment and is placed in the boiler house basement in front of the boiler unit. To provide for emergency conditions of operation it is advisable to install spare milling plant. The following data refers to two Unit systems :—

Boiler capacity . . .	110,000 to 130,000 lb. per hour M.C.R.
Number of pulverisers . .	3 (each 50 per cent. capacity).
Capacity of each pulveriser .	3 tons per hour (10 per cent. moisture in coal).
Number of burners . .	3.

Boiler capacity . . .	175,000 to 215,000 lb. per hour M.C.R.
Number of pulverisers . .	2.
Capacity of each pulveriser .	6 tons per hour.
Number of burners . .	4.

The burners are connected in pairs to the two mills alternately, so that when only one mill is working a normal flame distribution is obtained across the combustion chamber. The power consumption is 10 kWh. per ton of fuel milled.

Central System. This is sometimes known as the Bin and Feeder system, and may be arranged to serve the whole or part of a boiler plant (Fig. 183). The raw coal from the overhead bunkers is delivered to each mill through an automatic weigher if desired. From the mill, the pulverised coal passes through a classifier or separator which rejects and returns to the mill any oversize particles. The coal-laden air then passes from the classifier to a cyclone, the air being returned to the mill circuit by an exhauster fan. From the cyclone the pulverised coal is delivered to a bunker *viâ* a screw conveyor. When a boiler is taken out of service it is usually necessary to empty the pulverised fuel bin. The bins or hoppers are subject to spontaneous combustion and it is essential that the fuel be well dried and the bins perfectly airtight. It is possible to house the complete coal preparation plant in a separate building, but this has the disadvantages that greater site area is required and additional conveying equipment is necessitated. When the preparation plant is installed in the boiler house it is usual for one milling plant to serve this house only. On very large boilers two milling plants may be arranged to serve one boiler. The plant for this system is similar in many respects to that of the Unit system, as pulverisers and exhauster fans are essential items of plant. The additional items are cyclones, screw conveyors, fuel bins, fuel feeders, and primary air fans.

The feeders are situated immediately below the fuel bins. A screw conveyor extending the entire length of the storage bins is usual. The coal is dried in the mill either by hot air or flue gas which is forced through it and carries the powdered fuel to the cyclone where separation is effected. The fuel gravitates to the screw conveyors and is transferred to the storage bins whilst the hot air is extracted by an exhauster fan and returned to the mill. Where flue gases are used they are discharged into the boiler unit at suitable

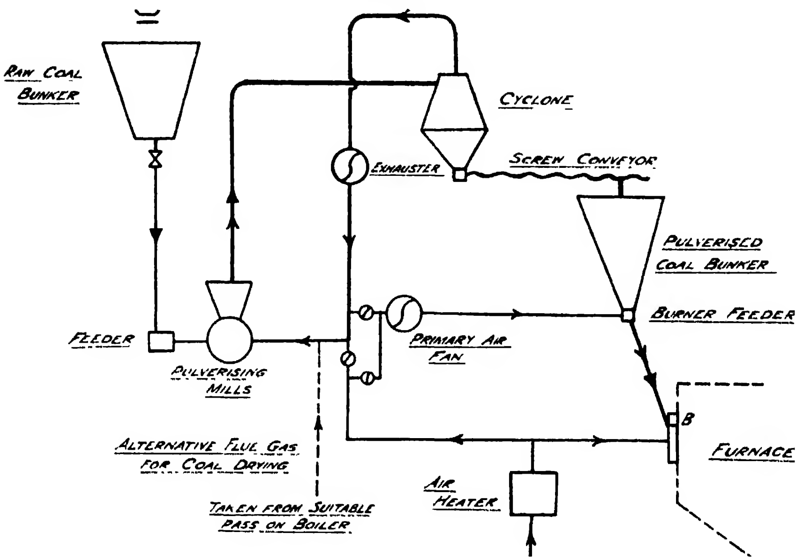


FIG. 183. Pulverised Fuel Central System.

positions. The temperature and dryness of the air circuit are maintained by regulating the admission of air from the air heater. The primary air-fan inlet is taken from the main air circuit with an alternative inlet in the exhauster fan discharge piping, the choice of air supply being effected by dampers. By isolating the drying supply of hot air or flue gas to the mills it is possible to operate the boilers with the milling plant out of commission.

Some idea of the installed auxiliary plant for unit and central systems will be obtained from Table 28.

Pulverisers. Pulverisation takes place in mills which may operate on one of several principles : impact, abrasion, crushing, etc. The chief requirements are that the fuel produced should not only be fine but of a consistent degree of fineness. The impact mill with its high-speed rotating hammers, the low-speed ball mill with its

TABLE 28. *Comparison of Central and Unit Systems of Pulverised Fuel Firing*

Draught Equipment, etc.			
Central -60,000 lb./hr. M.C.R.		Unit -130,000 lb./hr. M.C.R.	
	B.H.P.		B.H.P.
Induced draught	170	Induced draught	155
Forced "	100	Forced "	105
Primary air	80	Precipitator	2
Fuel feeder	4	Rectifier	2
Total	354	Total	264
Milling Plants			
Milling plant	335	Milling plant	960
Feeder drive	2	Feeder drive	10
Exhauster fan	245	Raw coal elevator	30
Raw coal elevator	30	Raw coal conveyor	7
Fuel conveyor	14		
Total	626	Total	1,007

Grand totals, draft and milling plants :
Central system : 60,000 lb./hr.—980 B.H.P., *i.e.*, 16·5 B.H.P. installed per 1,000 lb. of steam.
Unit system : 130,000 lb./hr.—1,271, *i.e.*, 9·8 B.H.P., installed per 1,000 lb. of steam.

cascading charge of steel balls and the medium-speed roller-and-bowl or ball-and-race mills all do their work effectively and the ultimate choice usually depends on the power consumption, maintenance and repair charges, etc. Mills may also be grouped into two classes, according to the manner in which the air stream is provided. In some mills an exhauster fan on the output side of the mill draws the air and coal mixture away ; in others, a pressure fan on the input side of the mill provides the necessary air current, the latter system having the advantage of requiring the fan to handle only clean air as already mentioned. The chief factors affecting pulveriser performance are coal "grindability," moisture content, and abrasiveness. Pulverisers or mills, as they are termed, may be high, medium or low-speed types. High-speed mills are usually of the revolving beater or paddle type with peripheral speeds averaging 18,000 ft. per minute, and output limited to some 5 tons per hour with power input of 18–20 kWh. per ton.

Medium-speed mills are of the roller or ball-ring type with peripheral speeds of 600–700 ft. per minute, and outputs of 10 tons per hour, with a power input of 10–15 kWh. per ton.

Low-speed mills of the tube type with ball charge operate at peripheral speeds of 450–550 ft. per minute, and have an output up to 20 tons per hour with power input varying from 20–25 kWh. per ton.

Pulveriser output will be limited to drying capacity rather than grinding capacity if the moisture content of the coal exceeds both that for which the pulveriser was designed and the drying temperature provided. Pulverisers applied to low moisture fuels can often be inadequate for high moisture fuels.

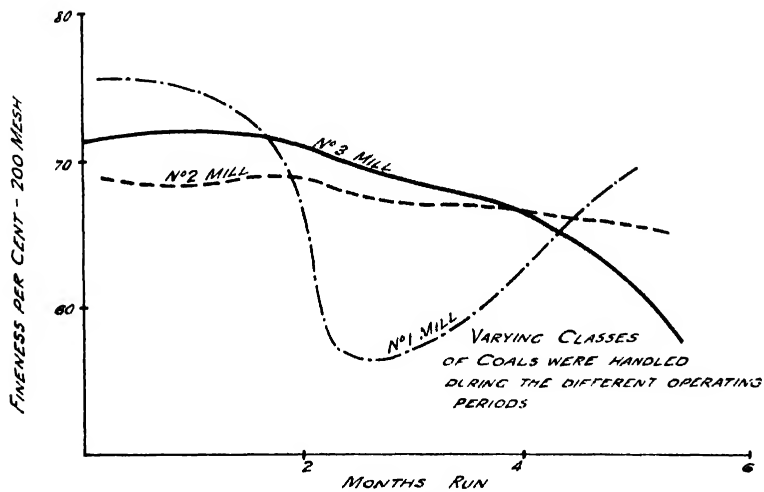


FIG. 184. Typical Milling Plant Characteristics (Hammer Type).

Flywheels added to mill motors help to hold fuel flames for up to fifteen seconds during momentary interruption.

Ball mills, in which steel balls are housed, are constructed of steel plates with renewable liners. In a 10-ton mill of this type, 28 tons of steel balls are used as the milling medium. The mill is capable of grinding 10 tons of coal per hour, containing not more than 4 per cent. moisture, to a fineness of 99 per cent. through a 100-mesh, 1 mm. sieve, and 85 per cent. through a 200-mesh, 1 mm. sieve (anthracite duff being used).

The hammer or beater types consist of a number of swinging hammers or rotating beaters for milling the coal. The hammers

are secured to a series of discs mounted on a centre shaft which is motor driven.

In another type the milling disc is of mild steel plate on which steel brackets are riveted, these brackets carrying renewable hard-wearing beaters. A throw-out door is included for the extraction of tramp iron carried into the mill. Pockets are also provided to trap these stray pieces of iron. The pulverising plant should be of simple design and robust construction to keep the maintenance charges, which are inevitable in this plant, within economic limits. Fig. 184 illustrates milling plant characteristics.

Coal Feeders. The feeders on unit pulverising mills have independent drives by a small-powered motor. The coal is fed by gravity from the bunkers, *viâ* a small hopper, on to the feeder. A chain-belt conveyor, rotary table or star feeder may be used. A star feeder is motor-driven through a worm reduction and crank on the worm wheel shaft connected to a ratchet and pawl device on the feeder shaft. The feeder motor may be interlocked with the mill motor so that in the event of the mill stopping, the coal-feed automatically ceases. The operators are sometimes relied upon for stopping the feeders.

Fuel Feeders. These take the fuel from the hoppers or bins and supply the burners. They are used on central systems. Having accepted the fuel from the hoppers it is then carried to the burners by hot air supplied by a primary air fan. The feeders are motor-driven from a common shaft, and any feeder can be de-clutched.

Separators. After the milling process the pulverised coal is withdrawn *viâ* a separator or classifier which rejects and returns to the mill any oversize particles. The degree of fineness of pulverisation is controlled by the position of a deflector which can be regulated. The coal-laden air passes from the separator to the burners, or in the Central system to a cyclone separator in which the fuel is separated from the air, the air being returned to the pulverising circuit by exhauster fan.

Cyclones. These are installed above the fuel hoppers and separate the fuel from the air. If a fuel transport pump system is used the fuel hoppers can be placed above the cyclones. Cyclones are conical steel containers into which the fuel and air pipes are led. The inlet pipe enters tangentially and the coal dust and air are thus given a rotating movement inside the cyclone. This causes the coal particles to be thrown to the sides and fall to the bottom, while the air moves to the centre and is extracted by the exhauster fan.

As the cyclones are below atmospheric pressure a motor-driven rotary air lock is included at the bottom to extract the fuel and prevent leakage of air into the system. A weighted flap valve is also used with success. Explosion doors are fitted in the top of the cyclone. The capacities of the cyclones are in accordance with the outputs of the milling plants.

Fuel Handling. Having deposited the fuel in the cyclones it now remains to be delivered into the storage hoppers or bins. This is carried out by screw conveyors, although other systems are available which make use of compressed air in conjunction with screw conveyors. The conveyors can be arranged to suit the bins, and the fuel outlets from the cyclones discharge either directly into the bin immediately below or into either of the two conveyors. The conveyors are of U-shaped section and have covers. Inside each a cast-iron or steel helix revolves, being supported by bearings. Openings with valves are arranged in the bottom of the conveyor for discharging the fuel into the bins below. In one system the fuel is delivered to a motor-driven fuel transport pump consisting of an enclosed screw conveyor which feeds the fuel into a stream of compressed air. By this means the fuel is transported through cast-iron piping to the fuel bins. The fuel transport pipes are so arranged that fuel can be delivered from any milling unit to any bin.

Fuel Bins. Steel plate construction with or without lining is usual, but brick lining with 1 in. rendering of cement has been used. An uninsulated steel bunker may give trouble due to condensation causing the fuel to adhere to the plates and finally become solid. The gunite lining is often reinforced by special slabs laid direct on the steel plates.

The fuel in the bins is liable to fire, and should the fuel reach a low level a clear hole or vortex may be formed in which case the feed to the burners is uncontrollable. Such a condition leads to excessive fuel being fed to the furnace resulting in rapid increase of boiler load. Nuisance is also caused by dense black smoke being emitted from the chimney. The holding capacity will depend on the storage desired, and in one installation the raw coal bunker of 600 tons, capacity serves two boilers of 300,000 lb. per hour M.C.R. and the capacity of each fuel bunker is 120 tons, there being one for each boiler unit.

Fans. The fans are those associated with the pulverising plant, namely, primary air and exhauster fans. The primary air fan in the Central system only handles clean hot air which it delivers to the burner or fuel feeders for conveying the fuel to the burners.

In this case its suction is connected to the air preheater outlet ducts (Fig. 183).

It is possible to have a common primary air duct system throughout the boiler house and so enable primary air supply to be maintained to any boiler in case of failure of its own fan. The fan is of the high-pressure low capacity type. The primary air fan in the Unit system handles hot air and fuel, and is subject to the abrasive action of the fuel. In this case it is essentially an exhauster. In some Unit plants it only handles hot air and need not be designed to withstand abrasion. The exhauster fans in the Central system draw air from the top of the cyclones and discharge it to the pulverising

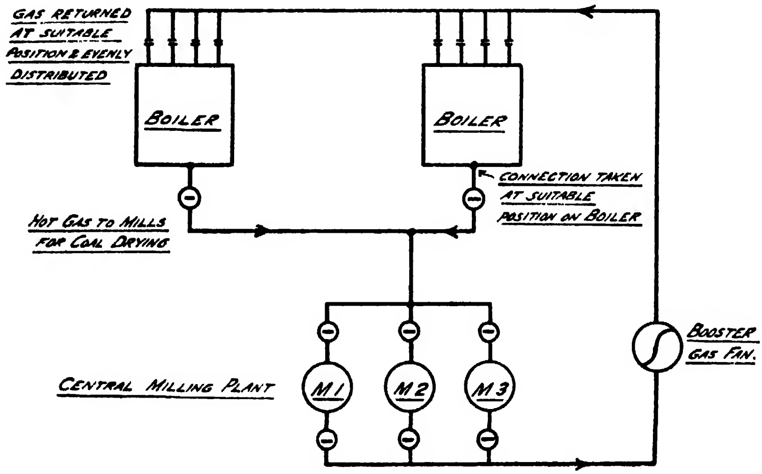


FIG. 185. Drying of Coal by Flue Gas.

mills. With this arrangement only a small proportion of the coal dust passes through the exhauster fan. Only a small section of the system (that between the mill and the exhauster) is above atmospheric pressure, consequently any leakage of coal dust is reduced to a minimum. Exhauster fans are of the unshrouded impeller type, the blades being easy to replace. The casings may have renewable linings.

Coal Drying. Coal drying facilitates grinding as it renders the coal brittle and non-sticky. The methods now in use are hot air and flue gas drying (see Figs. 157, 185 and 186). Steam drying was used in the early plants, but is now rarely adopted.

The hot air method is most favoured since it is simple and efficient. The drying air is taken from the preheater discharge ducting and passed through the pulverising mill in such a manner that a

proportion of the moisture in the raw coal is extracted before undergoing milling. The moisture remains in the system, and is discharged into the combustion chamber.

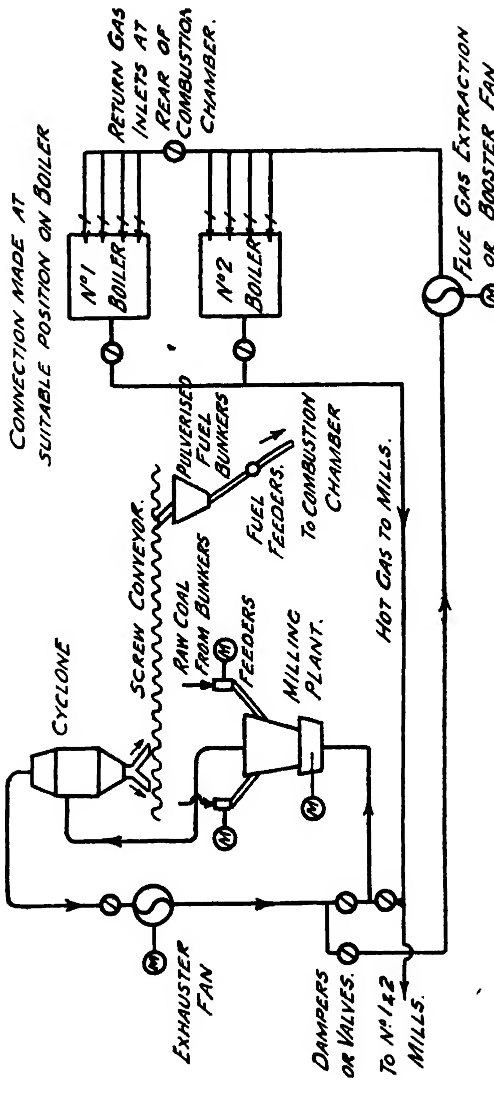


FIG. 186. Arrangement of Flue Gas Drying with Central System of Pulverised Fuel Firing.

Burners. The number and types of burners will depend primarily on the capacity and design of boiler. The burners mix the fuel and air intimately and project the mixture into the combustion chamber.

One type is designed in the form of a volute chamber into which the pulverised fuel and air mixture is fed. The secondary air, of which a given amount is necessary for complete combustion, is drawn from the preheater air ducts through adjustable vanes in the periphery of the burner. The air and fuel are thus thoroughly mixed and projected into the combustion chamber with a helical motion. The location of the burners depends on the design and construction of the boiler unit being disposed in the front vertical wall of the combustion chamber or arranged in arch construction over the front part of the chamber.

Burners may be divided into two types, namely, short and long flames, or turbulent and non-turbulent types. For normal bituminous coals the turbulent type of burner is usually employed since turbulence is an advantage in that complete combustion is achieved in the minimum possible time. There are various forms of this type of burner. The stream of primary air and coal is introduced through a nozzle and the secondary air is admitted through adjacent apertures arranged so that the air streams strike the main primary air-coal stream at an angle or with a swirling motion.

For low-volatile coals the velocity of the main stream must be kept well below the speed of flame propagation for the coal and particle size in question. A long, non-turbulent flame is required and the burners are often fixed so that they fire downwards, so that a long "U"-shaped flame is produced. Secondary air is provided through ports in the furnace walls at positions along the flame travel. The application of long-flame burners is chiefly in connection with the combustion of low volatile coals, such as anthracite. These burners project the flame downwards into the furnace, enabling the coal particles to follow as long a path as is necessary to ensure complete combustion before entering the boiler proper. The length of flame path is a function of the rate of flame propagation and the time required for combustion. These values are in turn dependent upon the class of fuel, the rate of flame propagation being largely dependent upon the volatile and ash contents. With low volatile fuels it is possible to obtain higher ignition and combustion rates by the following means :—

(1) Adoption of higher combustion air temperatures.

(2) Inclusion of refractory surface close to the burner ; this assists in maintaining ignition temperature.

(3) Delayed admission of secondary air until ignition has already taken place, thus enabling the preliminary admixture of hot furnace gases to have its maximum effect in raising the particles to ignition temperature.

Tangential firing is also used in which the burners are set at the corners of the furnace and fire tangentially to an imaginary circle near the centre of the furnace. This is often combined with tilting burners which enables the position of maximum heat release to be adjusted.

The burners are set in each of the four corners of the combustion chamber at such an angle that the directions of the coal and air streams leaving the burners lie horizontal and tangential to a circle of about 2 ft. at the centre of the combustion chamber. This promotes a vortex action in the flame, giving rise to a turbulence which ensures complete and rapid combustion of the fuel and effective and uniform distribution of radiation. One boiler of 525,000 lb. per hour (650 lb. 900° F.) capacity has three mills, each mill having four corner burners, which operate down to a very low duty.

Secondary air enters through the box enclosing the burner nozzles. The mills are arranged so that one mill supplies two diagonally-opposed burners. The auxiliary lighting-up burners are arranged along the side walls at operating floor level. It has been found that the refractories in the vicinity of the main burners are damaged by excessive heat and this has been overcome by providing a number of small holes in the combustion chamber wall around the burners to admit secondary air for cooling.

The particulars given in Table 29 relate to three installations.

TABLE 29. *Burner Details*

Boiler Capacity lb. per hour M.C.R.	No. of Burners	Type of Flame	System	Remarks
300,000	12 main 3 aux.	Long	Central	Burners in front arch of combustion chamber. U-shaped flame with a flame travel of approx. 50 ft. 3 aux. oil burners for lighting-up (compressed air).
215,000	4 main 2 aux.	Short	Unit	Burners in vertical front wall. 2 aux. oil burners (compressed air).
130,000	3 main 1 aux.	Short	Unit	Burners in vertical front wall. 1 aux. oil burner for lighting-up. (steam).

Lighting-up Equipment. The starting up of boiler plant after complete shut-down is of prime importance. For starting up

periods, when the boiler is cold and a slow firing rate is desired, a number of small capacity air atomising oil burners are used. The fire is started by inserting an oil torch through the tube in the burner front and then admitting primary air and fuel supply. A torch of waste dipped in oil and inserted in an observation hole may also be used. If the fuel does not ignite the torch should be withdrawn at once and the combustion chamber allowed to clear before attempting to ignite again. The secondary air is adjusted after the fire is going.

Pulverised fuel firing does not entirely eliminate standby losses, for losses are still incurred in bringing a boiler on to the range. Take the case of a 130,000 lb. per hr. M.C.R. boiler (300 lb. 750° F.) where oil lighting-up equipment is installed :

Condition 1.—From cold to steaming on the range, *i.e.*, full steam pressure 60 galls. of fuel oil consumed. Boiler brought up in three stages of pressure increase.

Condition 2.—Steaming on the range after being off for about 12 hrs. (Steam pressure at 180 lb.) 15 galls. of oil required.

Condition 3.—Steaming on the range, after being off about 2½ hrs., 9 galls. of oil required.

The fuel used was a standard Diesel oil :—

Viscosity (Redwood No. 1 at 100° F.)	40 secs.
Minimum closed flash point	150° F.
Maximum pour point	20° F.
Average calorific value	19,300 B.Th.U./lb.

In addition to the use of fuel for starting up, a small quantity is necessary after shutting down to burn the coal fuel remaining in the coal and air pipelines.

Starting up also entails the use of an amount of coal. Typical figures are :—

Lighting-up coal required, 0·75 ton when boiler has been off for about 18 hours.

Ditto, 0·4 ton when boiler has been off for about 8 hours.

Present practice favours the inclusion of an oil lighting-up equipment (Fig. 187) which incorporates one or more atomising burners per boiler. This is a fixed system, since the equipment is in a permanent position for all boiler units. The alternative is a portable air-compressor oil equipment which is transported to any unit to be commissioned. Creosote-pitch has also been used for lighting up pulverised fuel boilers.

The atomising or auxiliary burners depend for their operation

on either steam or compressed air. With a complete shut-down for any length of time steam will not be available and the compressed air system has much in its favour. Additional auxiliary plant is

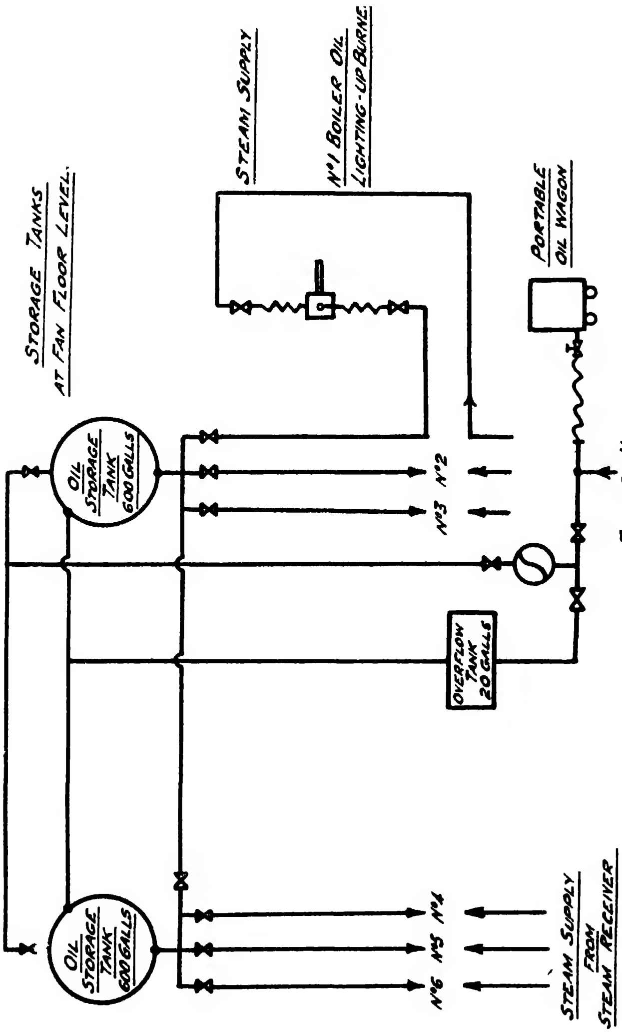


Fig. 187. Oil Lighting-up Equipment for Six Pulverised Fuel Boilers (each 130,000 lb./hr. 300 lb. 750°F).

necessary unless compressed air is required for other station services. A compressed air system has two motor-driven air compressors which maintain air receivers fully charged, and the oil fuel is delivered under pressure by rotary feed pumps so that lighting and re-lighting

may be carried out at short notice. It is possible to eliminate oil pumps by placing the oil storage tank at a high level to obtain the required head. Each boiler lighting-up equipment is then fed by a separate oil pipe from the tank. Steam is taken from the main steam receiver, so that a supply is always at hand. The steam is always on to the control valve at burner level. A small boiler may be kept for emergency service in the event of complete shut-down.

Pulverised coal burners are liable to go out when operating under low duty conditions with poor classes of coal, and to guard against this the oil system may be of the automatic type. The operator starts the fuel-feed pump by push button control and puts into action the ignition sparking to light the oil burners which in turn re-ignite the coal burners.

General. Data relating to two pulverised fuel-boiler plants are given :—

(1) C.S.G. Tri-drum boiler.

Evaporation lb. per hour	200,000 N.E.R. 240,000 M.C.R. 280,000 peak.
Heating surface . . .	13,230 sq. ft.
Steam pressure	625 p.s.i.
Steam temperature	850° F.
Feed ,, ...	350° F.
Combustion chamber . . .	27 × 20·5 × 24·5 ft. wide.
Radiant heating surface . . .	2,170 sq. ft.
Volume	16,930 cubic ft.
Rating B.T.U. per cubic foot per hour	18,650 M.C.R. 22,500 peak.

The fuel burnt is South Wales Anthracite Duff having the following analyses :—

Calorific value (as fired) . . .	12,500 B.Th.U. per lb.
Moisture	4 per cent. maximum.
Volatiles	6 to 8 per cent.
Carbon	74 to 80 per cent.
Ash	14 per cent.
Ash fusion temperature . . .	2,460° F.

Twelve burners of the " U " flame type are used.

(2) " Lopulco " boiler.

Evaporation lb. per hour	205,000 N.E.R. 256,000 M.C.R.
Heating surface (combustion chamber)	3,600 sq. ft.
,, ,, (boiler) . . .	4,400 sq. ft.
Steam pressure	625 p.s.i.
Steam temperature	825° F. controlled.

Feed temperature	340° F.
Combustion chamber	19 ft. 4 in. deep × 25 ft. 8 in. wide × 27 ft. 6 in. high.
Volume	13,700 cubic ft.
Rating maximum	23,600 B.Th.U. per cubic foot per hour.
Fuel (bituminous) gross C.V.	10,500 B.Th.U. per lb.
Ash	16·36 per cent.
H_2O	8·86 „
C	58·74 „
H	4·24 „

Corner fired on Unit system from two mills, rate of firing on maximum load being 31,600 lb. per hour (14 tons per hour).

Superheater M.L.S. :—

Total heating surface	11,300 sq. ft.

Economiser Senior Twin-tube :—

Heating surface, steaming	6,863 sq. ft.
„ „ non-steaming	9,608 sq. ft.

Air Heaters, " Usco " plate type :—

Heating surface, secondary	10,710 sq. ft.
„ „ primary	46,980 sq. ft.

The plant is designed for a guaranteed efficiency of 92 per cent. on the net calorific value of the specified fuel, the final gas temperature being reduced to 250° F. on normal load.

REHEATER BOILERS

When it is desired to re-superheat the steam after partial expansion through the turbine these boilers are employed.

To obtain temperature regulation the reheater unit has built into it a boiler which generates steam at normal boiler pressure for the main steam range. The reheater unit is a combination of a reheater, boiler, superheater, economiser and air-heater. The reheater is a low-pressure system in which the steam can be automatically cut off without risk of damage to the unit. It is started up like an ordinary boiler and the boiler portion is brought up to pressure and connected to the steam receiver. Steam generators for reheat are a little more complicated because the reheater section adds more heat per pound of steam as the load decreases, whereas the initial superheat adds the same number of heat units throughout the load range. Reheat temperature can be controlled by tilting

the burners at each of the four corners, initial superheat by steam desuperheater in addition to burner tilt. Four horizontal drums may be provided (a lower pair and upper pair), which are connected by tubes, a cross-connection being placed at one end of the two middle drums. Steam enters the upper drum passing downwards through the reheater tubes back to the turbine from the lower drum. A fully automatic system of protective controls is included to work in conjunction with the turbine. A relief valve fitted on the lower drum is set to blow off at a safe figure. The principles of reheating are outlined in Chapter IX.

The Dunston "B" station embodies reheating equipment. The plant particulars are as follows: each 50 MW turbo-alternator operates at 600 p.s.i. and 800° F. at the stop valve. Two boilers and two reheater boilers serve each turbine, the latter being situated in the boiler house near the end adjoining the turbine house. This reduces the length of pipework from the turbine to the reheater boilers. The initial installation consisted of three 50 MW turbo-alternators and the following boiler plant:—

Four	156,000 lb. per hour M.C.R. stoker-fired boilers.
Two	156,000 ,, ,, ,, pulverised fuel boilers.
Four	125,000 ,, ,, ,, stoker-fired reheater boilers. Approximately 180,000 lb. per hour of steam is reheated from 520° F. and 115 p.s i. to 825° F. at the same pressure.
Two	125,000 lb. per hour M.C.R. pulverised fuel reheater boilers. Also capable of reheating 180,000 lb. of steam per hour under above conditions.

The boilers have a safety-valve load of 710 p.s.i., the final temperature being 840° F. Under normal operation the temperature of the reheated steam to the turbines is maintained at a constant temperature of 825° F. by a system of automatic controls. Subsequent plant extensions at this station provided for reheating under the same steam conditions and an overall thermal efficiency of 29·59 per cent. has been obtained.

The largest unit under construction in this country is of 120 MW. capacity at 1,600 p.s.i. and 1,010° F. reheating to 1,050° F., and the boiler will have a capacity equivalent to more than 1,000,000 lb. per hr. straight evaporation which should enable a high efficiency to be obtained.

FORCED CIRCULATION BOILERS

Much attention has been directed to the use of very high pressure boiler plants, two of the most common being the La Mont

and Loeffler. Fig. 188 illustrates other types. Just as mechanical induced and forced draught has displaced natural draught to enable the high rates of combustion to be achieved, so means of mechani-

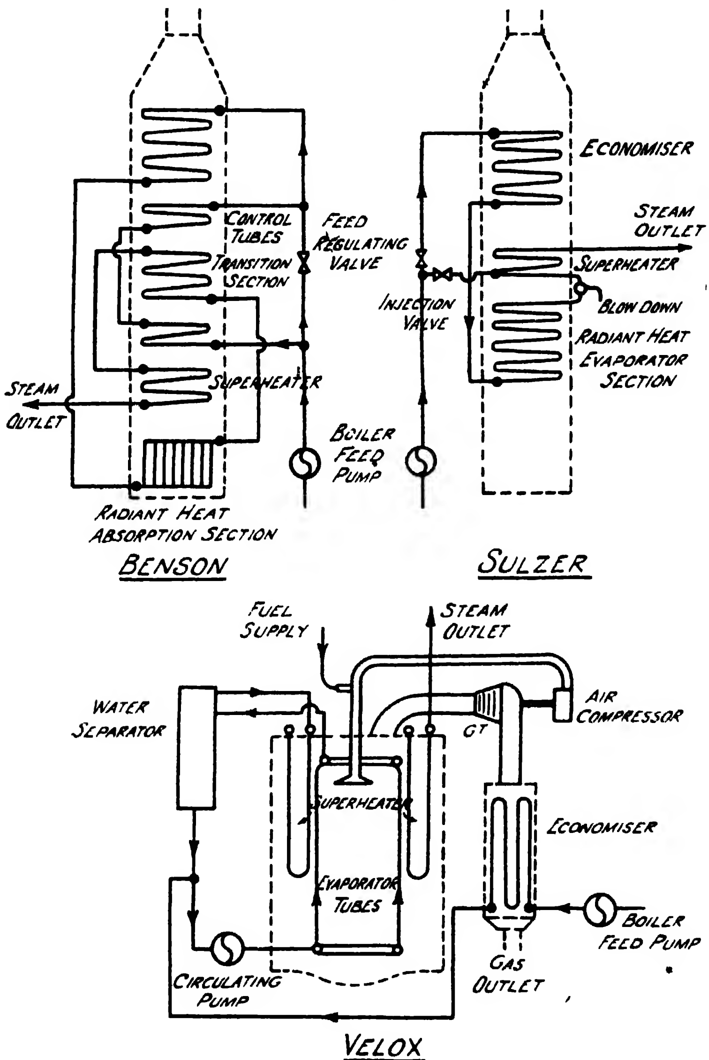


FIG. 188 Alternative High Pressure Boilers.

cally assisting the indefinite and variable factors associated with natural circulation have been adopted. The use of higher steam pressures has done much to bring the forced circulation boiler to the

fore due to the fact that as the pressure is increased the relative densities of steam and water at saturation temperature (upon which thermo-syphonic circulation or "natural circulation" depends) alter so much. Table 30 shows the variations and Fig. 189 shows relationship between pressure and volume.

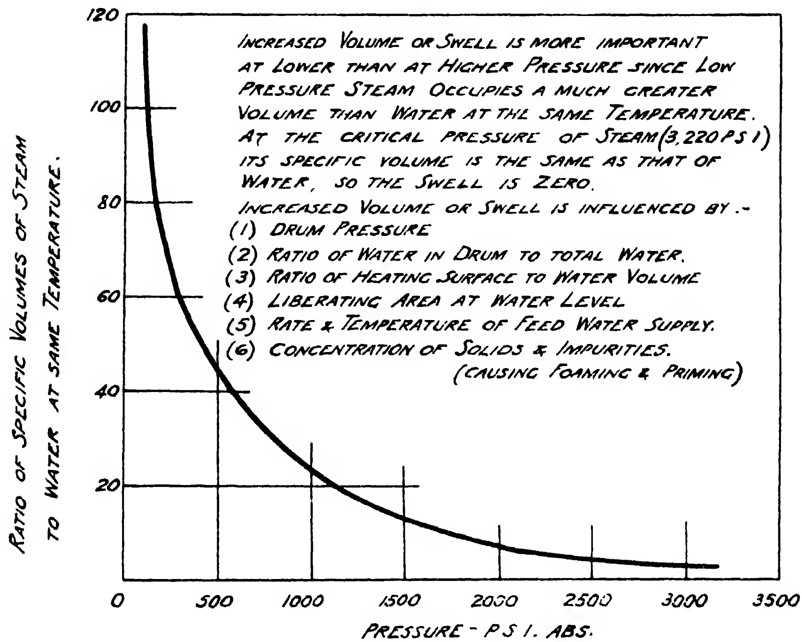


Fig. 189. Relationship between Pressures and Volumes for Steam and Water.

TABLE 30. *Variation of Density of Saturated Steam and Water*

Steam Pressure (lb. per sq. in. abs.)	Density of Saturated Steam (lb. per cubic foot)	Density of Water at Saturatio Temp. (lb. per cubic foot)
200	0·44	54·4
350	0·75	52·3
600	1·29	49·8
1,200	2·77	43·6
1,500	3·61	41·8
2,000	5·30	39·2

Other advantages claimed for forced circulation are :—

(1) Use can be made of smaller bore and thinner tubes for the higher working pressures.

(2) The number of steam and water drums is reduced.

(3) The heating surface can be disposed to obtain the greatest advantage of heat transfer.

(4) Increased evaporation in a given building space.

(5) Reduced weight with saving in foundations and lower cost per unit output.

(6) Scale formation troubles inside the tubes which are allied to sluggish circulation are minimised.

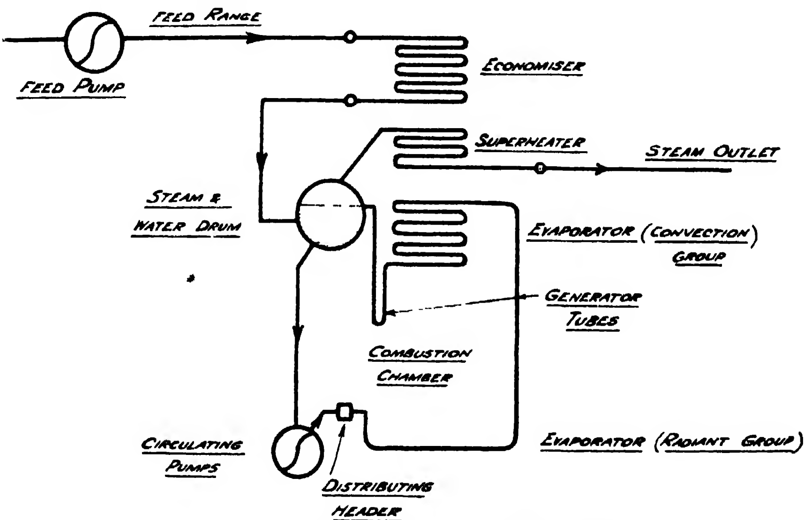


FIG. 190. Diagram of Typical La Mont Boiler.

On the other hand the unit is complicated by the inclusion of special pumping plant which absorbs power continuously. To guard against failure of this plant it is also necessary to provide elaborate protective devices and controls.

La Mont Boiler. The general features of this boiler will be understood in referring to Figs. 190 to 192. The system comprises a steam and water drum from which the water is taken to the circulating pumps and delivered to the distributing header. From this header it is distributed to the generator tubes by orifices or nozzles, one of which is inserted at the entrance to every tube, the size of the nozzle being such as to ensure correct distribution of water to each generating tube. The feed pumps, economiser and superheater are of standard design. The steam and water drum

(there may be two in very large units) is placed in any suitable position, and no part of the drum need be exposed to hot gases. The drum is relatively smaller than that of a natural circulation boiler due to the very high rate of water circulation throughout the boiler. The circulating pumps are of standard design with a single impeller and the glands and bearings are water cooled. The pumps are designed to run at constant speed irrespective of the boiler output and the amount of water circulated is about five to eight times the boiler output. The power absorbed is small and is more than counterbalanced by the saving in radiation loss,

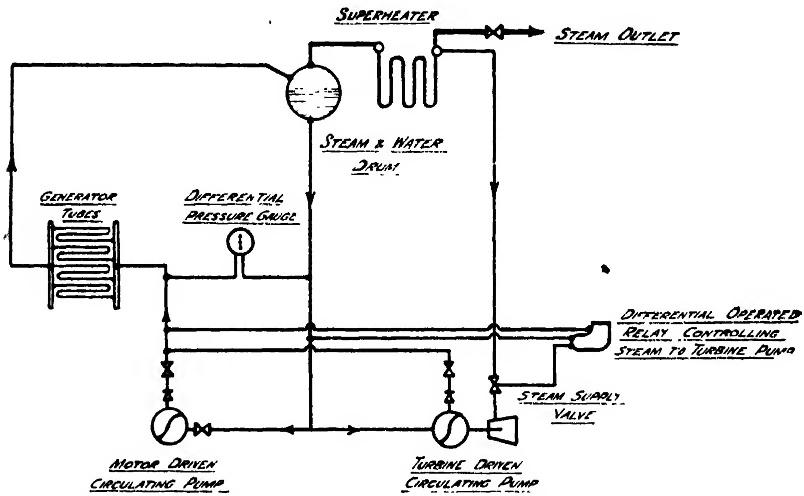


FIG. 191. Diagram of Circulating Pump System for La Mont Boiler.

due to the small size of boiler and the saving in mechanical draught requirements. A stand-by steam turbine-driven pump may be included and arranged for automatically coming into circuit in the event of electric pump failure. The circulating pumps discharge the water in the headers at a pressure of 30 to 40 p.s.i. above the pressure in the drum. The heating surfaces throughout are formed of small bore tubing (approximately 1 in.) arranged as a large number of elements ; each element may consist of a number of tubes welded together and bent to the desired shape, the various tubular elements being connected in parallel so far as water circulation is concerned. Full circulation may be started before lighting up and maintained throughout the steam-raising period, thus ensuring equal and steady increase of temperature throughout the boiler and

eliminating the possible risk of strains due to unequal expansion. This boiler is capable of extremely rapid raising of steam; a 220,000 lb. per hour unit has raised steam from cold to full load in twelve minutes and from warm stand-by conditions in about four minutes. It is used for both medium and very high steam pressures, as will be noted from the following examples:—

350,000 lb. per hour capacity	.	385 p.s.i. and 780° F.
40,000 ,, ,, ,,	.	1,000 ,, and 850° F.

Loeffler Boiler. This (Fig. 193) is another form of high pressure forced circulation boiler, but differs in principle to the La Mont. A proportion of the superheated steam passes into the water in the evaporating drum and results in an increased quantity of saturated steam entering the steam circulating pump. Usually about one-third of the steam is taken to the high-pressure turbine, the remainder returning to the evaporating drum to complete the cycle. The steam is discharged below water level through nozzles. This steam evaporates the feed water when the boiler is working, but for starting-up purposes an external supply of low-pressure steam is required. The generation of steam in the evaporating drum is silent and the pump develops a head of about 70 p.s.i.

The advantages claimed by this system of steam generation are:—

(1) Controlled steam circulation which facilitates the maintenance of uniformly high steam temperatures under all working conditions. A high velocity of dense steam over the heat-absorbing surfaces and consequently a low temperature difference between tube and steam. It is also able to respond rapidly to sudden variations in load.

(2) The use of clean dry steam as the medium for absorbing the heat liberated in the combustion chamber ensures absence of boiler scale.

(3) The blow-down losses are reduced since the boiler can work with a higher degree of concentration of salts than is desirable in ordinary boilers.

(4) Simplicity in design and construction effects considerable saving in building construction and lends itself to adoption in reconstructed buildings.

The steam circulating pump maintains a positive circulation of steam through the tubes exposed to external heat. By adjustment of the pump speed the quantity of steam circulated can be varied over a wide range to conform with the steam output required, and by the same adjustment the final steam temperature may be maintained without variation in spite of changes in load and alteration of combustion chamber conditions.

Sudden demands for steam may be met without waiting for an increase in rate of combustion since an increase in the speed of the

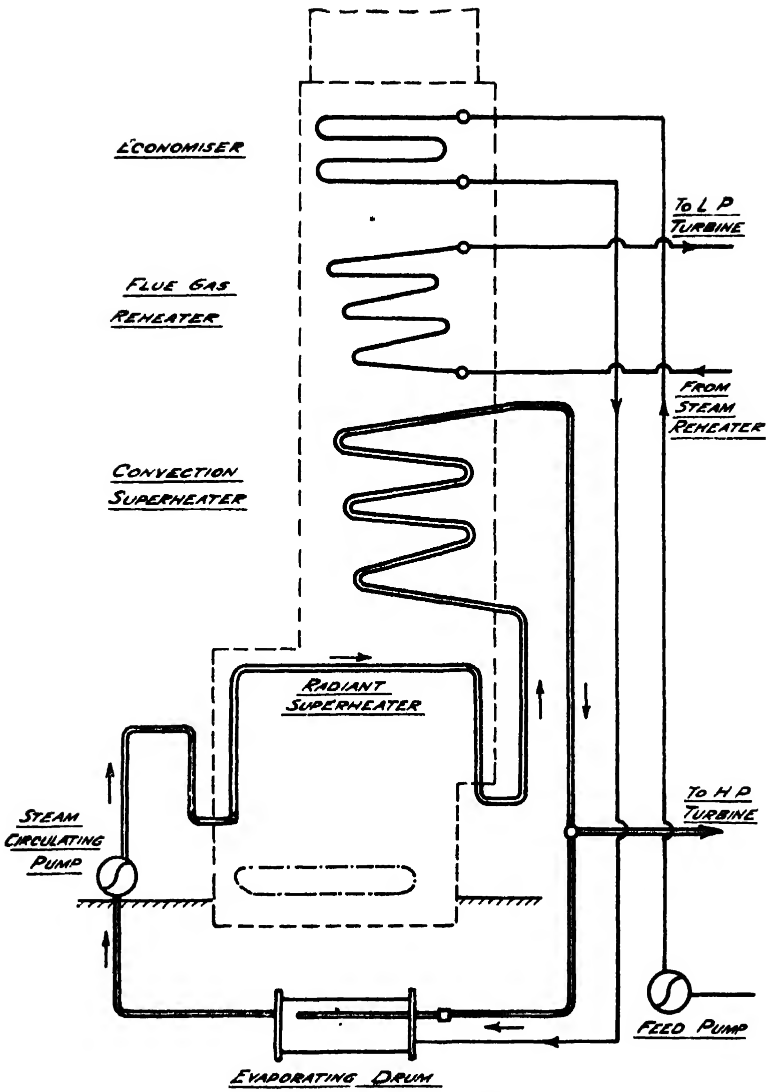


FIG. 193. Diagram of Loeffler Boiler.

pump with a consequent increase in steam velocity enables heat to be extracted from the walls of the tubes which act as heat accumulators. For a short period a large increase in load can be carried without any appreciable drop in steam temperature. The pump is driven by a low-pressure steam turbine the steam for which may be

bled from the main turbine, the exhaust steam being utilised for feed water heating. Whilst the pump has to withstand the full boiler pressure the power required for its operation is only that necessary to overcome the resistance to the flow of steam through the circuit. A brief description of the first installation in Great Britain of this type of boiler will suffice to illustrate its application. The plant is installed in Brimsdown Power Station.

Boiler steam conditions are 2,000 p.s.i. and 940° F. Two boilers—each 210,000 lb. per hour M.C.R. capacity. Designed annual thermal efficiency 30 per cent. The plant particulars are as follows :—

Three Evaporator Drums. Plain cylindrical forging having internal dimensions 3 ft. 7 in. diameter, 27 ft. long and shell thickness $3\frac{1}{4}$ in. The ends are of flat plates 12 in. thick screwed into the drum and seal-welded, an external shrunk ring also being fitted. All connections are arranged on the drum-ends and a manhole is provided at one end for inspection purposes. The material is 36 to 40 tons Siemens acid open hearth steel.

Steam Circulating Pumps. One per boiler, of the single-stage type with over-hung stainless steel impeller, driven by variable speed steam turbine having one velocity and six impulse stages at 2,000 and 6,200 r.p.m. The steam supply is obtained from the auxiliary system and is exhausted from the turbine into the de-aerating and evaporating plant.

Radiant Superheater. Heating surface 2,230 sq. ft. made up of 192 chrome-molybdenum steel tubes $1\frac{1}{16}$ in. external diameter and 0·232 in. thick. Outlet temperature 780° F. All-welded construction with flanges at suitable points to facilitate dismantling.

Convection Superheater. Heating surface 8,600 sq. ft. made up of 114 coils in chrome-molybdenum steel tube $2\frac{1}{16}$ in. external diameter and 0·244 in. thick. The tubes are arranged at a horizontal pitch of $2\frac{1}{2}$ in. (staggered) and a vertical pitch of 8 in.

Flue Gas Reheater. This reheats the steam at 200 to 240 p.s.i. from about 480° F. to 820° F. It comprises two 25-in. internal diameter carbon steel drums connected by 228 2-in. external diameter tubes giving a total heating surface of 6,800 sq. ft. The tubes are in the form of hairpins and expanded into the drums. There are two passes on both steam and gas sides.

Economiser. Heating suface 24,938 sq. ft. designed to heat the feed water from 330° F. to 520° F.

Air Preheaters. Two per boiler. Total heating surface 23,360 sq. ft. Designed for :—

Air 332° F. and gas 278° F. M.C.R.
Air 314° F. and gas 251° F. N.E.R.

Stoker. Twin type—25 ft. wide by 23 ft. long.
Grate area 575 sq. ft.

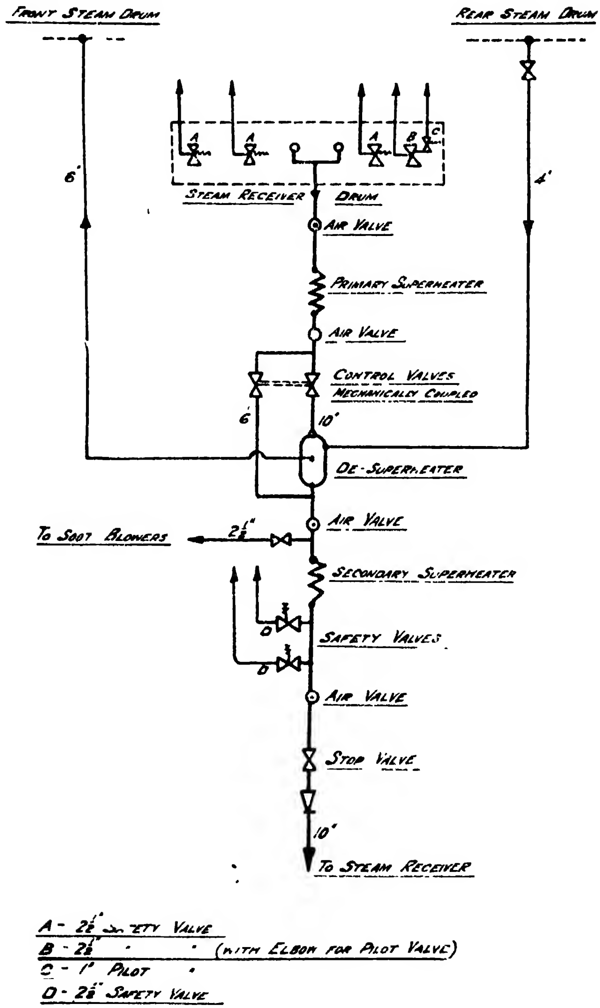


Fig. 194. Boiler Steam Pipework.

Twenty-two secondary air nozzles in front wall of combustion chamber arranged so that alternate ones can be cut out of service on light load. The boiler units are of welded construction, the welding being built separately in the form of a strong reinforcement

at the joints. After completion it was normalised by heating to between 890° to 930° F. by means of a sectional gas burnor and then allowed to cool very slowly. Small bore tubes were brought up to temperature by means of an oxy-acetylene torch and then allowed to cool in a small muffle. The majority of the welds in the boilers, headers and external piping were X-rayed to ensure a high standard. There are no expanded joints in the high pressure parts of the boilers.

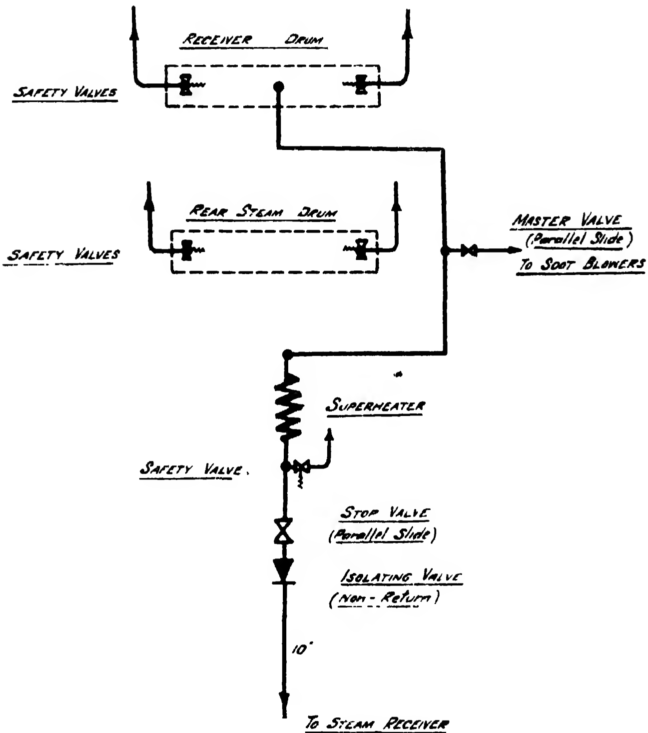


FIG. 195. Boiler Steam Pipework.

A steam turbine drive was considered the simplest and most reliable for the steam circulating pumps where a wide range of speeds was required.

MOUNTINGS AND FITTINGS

The mountings and fittings required will depend upon the steam pressure and boiler capacity.

Valves. A list of valves for a 190,000 lb. per hour, 700 lb. p.s.i. boiler is given.

Main steam stop valve at superheater outlet.
Main automatic isolating valve at superheater outlet.
Feed check valves—controllable non-return with cushioning dashpot.
Feed regulating valves—controllable non-return with cushioning dashpot.
Feed control valves—for isolating purposes.

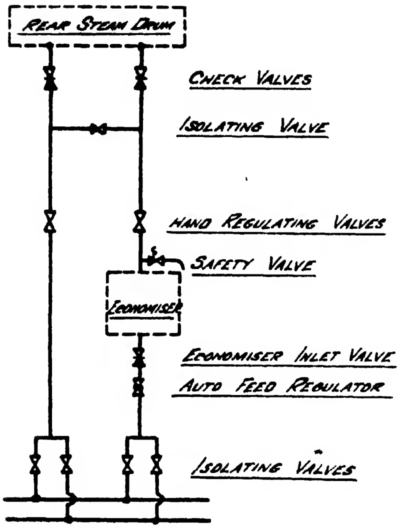


FIG. 196. Boiler Feed Pipework.

Boiler safety valves—spring-loaded high lift, one valve to have pilot safety valve.

Superheater safety valve—spring-loaded high lift.

Economiser safety valve—spring-loaded valve.

Economiser feed inlet valve—controllable non-return with cushioning dashpot.

The Hylif safety valve (Hopkinsons Ltd.) provides a valve of maximum discharge capacity for high-duty boilers. When the steam pressure rises to the set value, the valve discharges with a small lift, on the principle of an ordinary safety valve. This initial opening allows the escaping steam to exert its pressure over the full area of the valve face and increases the lift until the face of the valve enters the valve guide, when the steam is deflected downwards by the edge of the guide and the consequent reaction pressure lifts the valve to its full-open position. At this initial stage of valve lift, the discharge area between the seat and the valve equals the net area through the seat and the discharge capacity has reached its maximum. When the discharge pressure has been relieved the valve begins to close and as it emerges from the valve guide the reaction ceases and the valve shuts down cleanly.

The safety valve settings may be as follows :—

Designed drum pressure . .	710 p.s.i.	
Superheater	655 ,,	(two valves).
Boiler—1st valve . . .	695 ,,	
2nd ,, . . .	700 ,,	
Boiler—3rd valve . . .	700 ,,	
4th ,, . . .	750 ,,	
Pilot Valve on 4th Valve . .	655 ,,	
Economiser Safety Valve . .	875 ,,	

In addition, each boiler is fitted with the necessary blow-down and drain valves. The valves required and their positions are shown on Figs. 194 to 198.

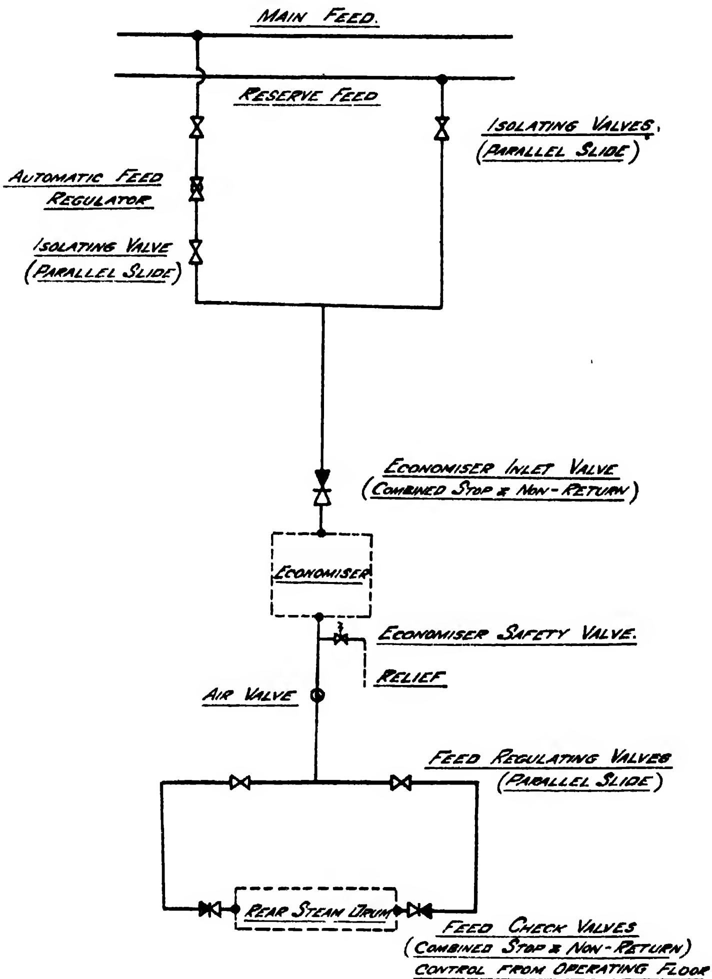


FIG. 197. Boiler Feed Pipework.

Superheater safety valves are sometimes fitted with a stop valve in series to isolate the safety valves after blowing and facilitate repairs without taking the boiler off the range. The superheater safety valves usually have lower settings and blow-off first thus

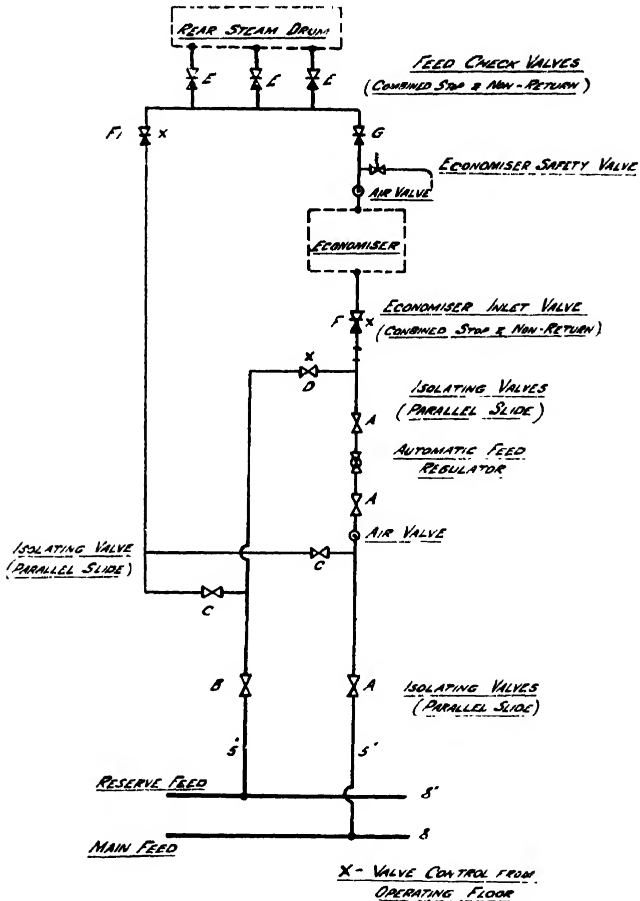


FIG. 198. Boiler Feed Pipework.

Reference	Type of Valve	Service	No. off
A	5 in. Parallel Slide .	Main Feed	3
B	5 in. Parallel Slide .	Reserve Feed	1
C	5 in. Parallel Slide .	Direct Feed and Regulator By-Pass	2
D	5 in. Parallel Slide .	Regulator By-Pass . . .	1
E	$3\frac{1}{2}$ in. Stop and Non-Return.	Boiler Feed Check . . .	3
F	5 in. Combined Stop and Non-Return .	Economiser Inlet Feed, "Controllable."	1
F_1	5 in. Combined Stop and Non-Return.	Direct Feed Hand Regulation .	1
G	5 in. Combined Stop and Non-Return.	Economiser Outlet Feed, "Controllable."	1

ensuring passage of steam through the superheater, and preventing over-heating of tubes.

Feed Water Regulator. Control of feed water to boilers is afforded by automatic and hand-regulated valves, the former being actuated by the varying water level in the boiler drum. An automatic feed regulator governs variations in the water demand of the boiler and stabilises the level in the drum. The regulator should be capable of adjusting the pressure difference across the valve due to varying pressure in the feed water system.

The Cope's "Flowmatic" regulator (Fig. 199) is responsive to the rate of steam demand as measured by pressure drop across the superheater, with an over-riding control by water level in a thermo-

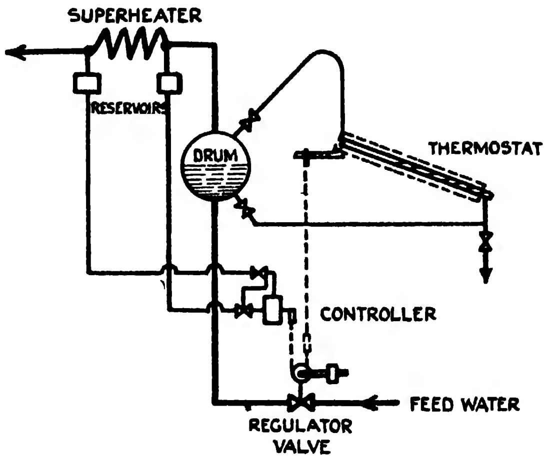


FIG. 199. Flowmatic Feed Controller. (Copes Regulators Ltd.)

stat tube. A sudden increase or decrease in steam demand thus ensures a corresponding adjustment of feed flow before the water level has sensibly altered.

Feed regulators incorporate steam and water-flow governing with an over-riding drum level control as a safeguard against changes of water volume with rapid load variations.

Some types of regulators cut off the water completely and rapidly, and are liable to set up surges and water hammer in the feed lines.

High and Low Water Alarms. External type with whistle indicating a low level distinct in tone from that indicating a high water level are included. Guards are provided to prevent a dangerous discharge of steam.

Repeated testing of high water alarm may result in carry-over

of water and salts to superheater causing deposits in tubes to such an extent as to overheat them and cause failure due to bulging. High water level causes priming. The alarms may be tested by isolating the steam and water sides from the drum.

Water Level Indicators. Two water level indicators are fitted, one on each end of the rear steam drum. The Factories Act requires one water level indicator. The range should be such that swelling and shrinkage of level due to load change is allowed for. There should be a definite indication of the water column in two colours, visible at a height of about 5 ft. above

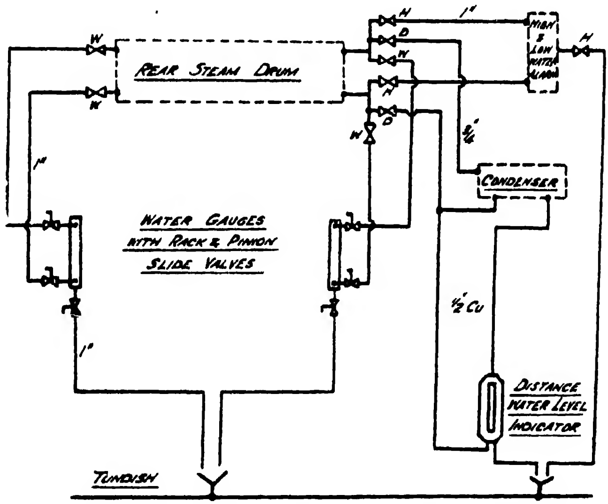


FIG. 200. Water Alarm, Gauges and Indicator.

D—¾ in. slide valves.
H—1 in. slide valves.
W—1 in. slide valves.

operating floor level, and a remote water level indicator (Figs. 200 and 201) may also be included. The water pipes from drum to gauges should be level otherwise incorrect levels may be indicated. There is a difference in density between the water in the boiler and that in the gauge glass. Water in the boiler is lightened by steam bubbles and is also warmer. A difference in level may be noted after blowing glasses down. Incorrect levels are also possible due to the varying temperatures of water in glasses and drums. Incorrect level in the two- and three-drum types is primarily due to the above, whilst pressure differences occur in each drum and force the level in one with corresponding reduction in the other.

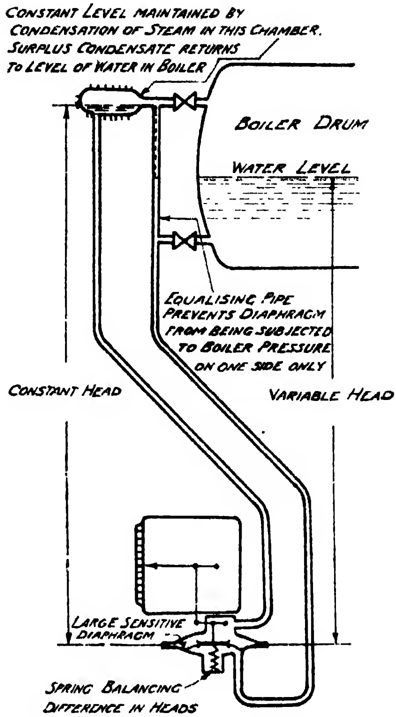


FIG. 201. Remote Water Level Indicator. (Hopkinsons Ltd.)

Television has been used in America for viewing the boiler gauge levels in the control room which is placed midway between the turbine and boiler houses.

Sampling Apparatus. A connection to the lower (mud) drum (Fig. 202) enables samples of water to be withdrawn for testing purposes. If water treatment such as phosphate charging is in use, a sample from the steam drum is necessary to ascertain if carry-over is taking place. A small tubular condenser or a coiled tube in a bucket of water is quite satisfactory.

Sooting and Cleaning of Boilers. A most important item in efficient boiler operation is the regular cleaning of soot, dust and deposits from tube and element surfaces since any form of deposit will reduce heat transfer. The essential requirement of a soot blower is that the nozzle should give a jet of uniform velocity, without the risk of scouring or thinning tubes by an excessive velocity in some part of the jet. The blower should also rotate to reach every part of the area in which it is located. Soot blowers (ash or fly-ash blowers, since very little soot should be present if good combustion is maintained) should maintain the external heating surfaces of boiler, superheater, economiser and air heaters in a clean and efficient condition. The blowers may use superheated steam, saturated steam or compressed air. Superheated steam is usual but saturated steam is better since the effectiveness of a soot blower

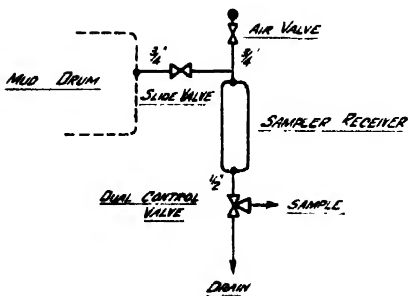


FIG. 202. Sampling Apparatus.

depends on the dynamic force and there must be mass as well as velocity.

Compressed air is expensive since a compressor is required, and unless heating is incorporated the air enters the boiler-gas passages

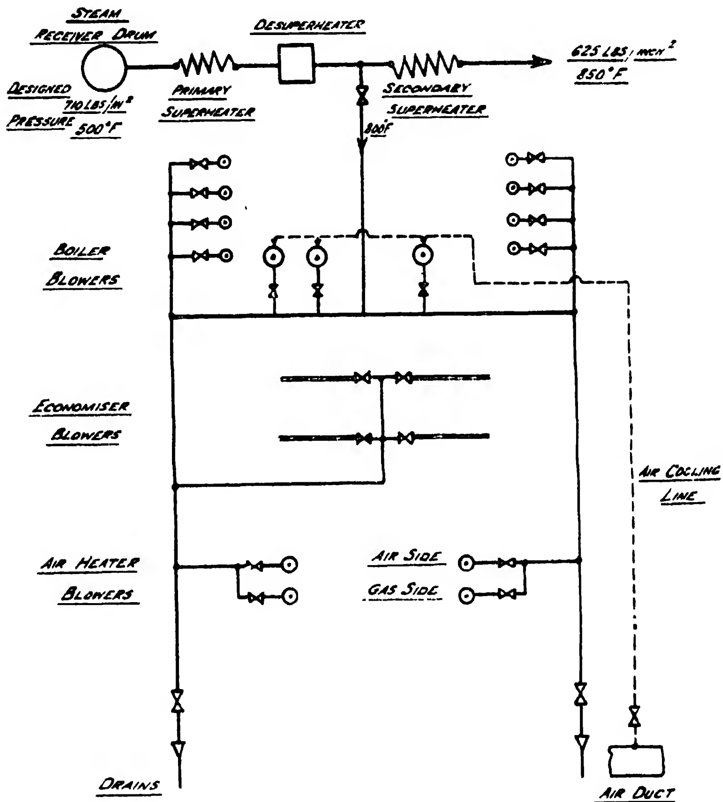


FIG. 203. Layout of Soot Blowers for 190,000 lb. per hour Boiler.

Boiler Unit.—Three single-nozzle type blowers through front wall of combustion chamber.
Four multi-nozzle type blowers to clean superheaters.
Four multi-nozzle type blowers to clean last two passes of the boiler.

Economiser Unit.—Four special type blowers.

Air Heater Unit.—Two special slotted nozzle type blowers.

at a low temperature. Compressed air at 120 p.s.i. has been used on air heaters. It is possible to cool the gases below their dew-point, causing corrosion in the neighbourhood of the blowers. The blower piping is thoroughly warmed and drained before commencing blowing operations to reduce deposits on economiser, superheater

and air heater tubes, etc., as a result of moisture. Soot blowing with both air and steam appears to offer better results than either medium alone. So far as effectiveness of soot blowing is concerned, superheated steam may be regarded as an intermediate stage between saturated steam and compressed air. It has been found necessary to discontinue steam soot blowing on some economisers to increase the length of time between cleanings.

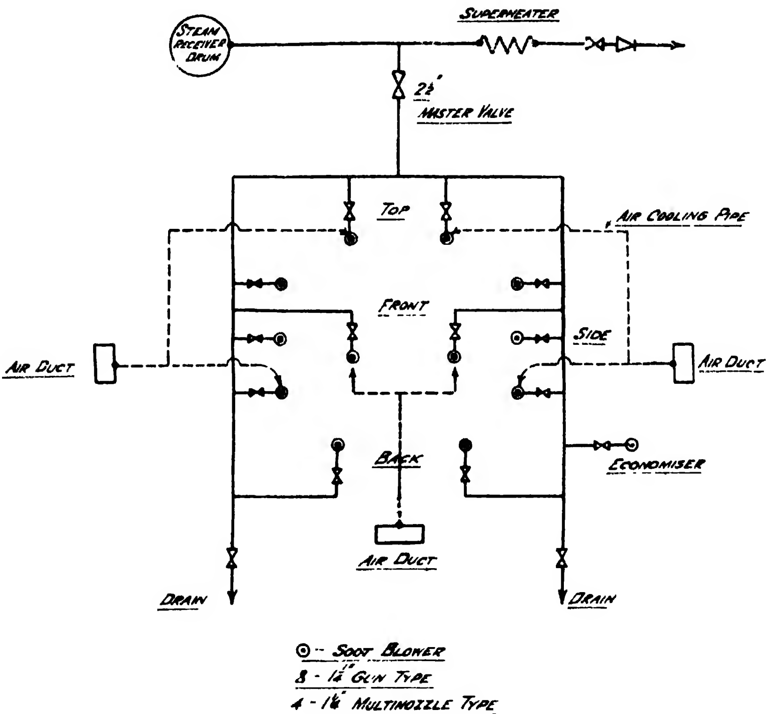


FIG 204. Layout of Soot Blowers for 130,000 lb. per hour Boiler.

For efficient soot blowing the position of the blowers is important. The nozzles and tubes of the blowers in the boiler are subjected to high working temperatures and should be designed and constructed to withstand these. In the cooler parts of the boiler non-retractable blowers are used, but in the hot parts, the blowers advance into the furnace, rotate and blow, and are retracted again. For difficult locations, a device known as the rack-type blower is used, which has a very long retractable head, having two nozzles at the end. As it enters the furnace, it revolves, so that the jets trace out a helical

path. Calorised tubes are employed and the following relate to a set of blowers fitted to a large stoker-fired boiler and operate at a pressure of 700 p.s.i. and 750° to 800° F.

Three blowers in front wall of combustion chamber.

Non-withdrawal gun or single nozzle type. Nozzle to rotate through 360°. Nozzle is a malleable casting treated on the outside by a special heat process and guaranteed for a continuous temperature of 1,000° C.

Four blowers to clean superheaters.

Non-withdrawal multi-nozzle type.

Two rotate through 120°.

Two rotate through 155°.

Elements of weldless hot-drawn mild steel specially heat treated on the outside, including nozzles, guaranteed for a continuous temperature of 1,000° C.

Four blowers in last two boiler passes.

Two rotate through 215°.

Two rotate through 250°.

Elements of weldless hot drawn mild steel.

On large modern boiler plants it is now usual for the soot blowers to be operated in the correct sequence so that deposits are not blown from one location to another which has just been cleaned. This is carried out by automatic timing and control gear operating through electric or hydraulic servo-mechanisms.

Facilities should be provided for washing out a boiler internally, a water system with hose pipes being usual for tube cleaning, etc. An electrically-driven scaling tool, with an adequate length of flexible shaft, a range of cutter heads and brushes together with sets of tube expanders and cutters are provided in the maintenance equipment.

Figs. 203 and 204 show two soot blowing arrangements.

Water Lancing. Water lancing of superheaters has been resorted to in an endeavour to extend the availability of boiler plant. Some idea of the data collected will be obtained from Table 31.

Care is necessary when carrying out water lancing, especially after a reasonably long (800–1,000 hours) period, otherwise there may be a sudden drop in superheater outlet temperature resulting in straining of joints with consequent leakages. Such effects have been observed on two-stage superheaters where the bottom half of one secondary superheater became choked and aggravated conditions.

The type and position of superheater will affect operating conditions relative to water lancing and each case must be considered on its own.

TABLE 31. *Water Lancing of Superheaters*

Items	Units	Stations		
		"A"	"B"	"C"
Boiler M.C.R. capacity	lb./hr.	170,000	250,000	200,000
Load during lancing	,,	170,000	200,000	180,000
Coal consumption	tons/hr.	7	10	9·5
Number of spraying points	2/side	4	4	4
Spraying time at each point	min.	30	150	20
With extension	,,	15	75	10
Without ,,	,,	15	75	10
Total lancing time	Hr.	2	10	1⅓
Steaming periods between lancing	,,	1,000	500	200
Dia. of pipe	in.	1	1	1
$\frac{5}{32}$-in. holes in pipe	No.	6	8	6
Water pressure	p.s.i.	45	80	100
,, consumption rate	g.p.h.	630	1,200	1,300
Water through boiler between lancing periods :—	est'd			
Combustion of fuel	tons	3,700	2,500	1,050
Soot blowing	,,	460	310	180
Water lancing	,,	6	50	7
Gas outlet economiser	°F	370	360	560
,, ,, Air heater	,,	350	300	290
Steam temp. at superheater outlet before lancing	,,	800	790	840
Ditto after lancing	,,	825	805	850
Type of superheater	-	Single-stage Horizontal	Three-pass Inclined	Two stage Horizontal

The water spray should be kept away from brickwork, tube headers, superheater supports, etc. Failure of superheater blowers to prevent choking and consequent reduction in steaming hours (800–1,000) and the fact that a gang of men is required for hand-cleaning has led to greater use of water lancing.

Steaming hours per boiler have now risen from 1,000 to 15,000, and although the efficiency is impaired during lancing periods, this method is simple and requires little maintenance. Water lancing is done while the boiler is on load and preferably with the air heater by-passed on the air side so that the temperature of the air heater elements is the same as the exit gas temperature.

General. Boiler availability was improved on one pulverised fuel station by the following : (1) Efficient and adequate number of soot blowers suitably placed and operated once per 8 hr. shift ; (2) Spacing and staggering of tubes in front bank ; (3) Unit system—no discharge flue gases used for coal drying ; (4) Air heater—copper-bearing steel for plates and wider spacing developed in gas path (increased from ⅝ to ¾ in.). There are two types of external deposits —high temperature and low temperature. The effects of the former appear to have become more severe as the surface temperature of the

boiler and superheater tubes has increased with the continued increase in steam pressure and temperature and in some stations with an increase in sulphur or chlorine content of the coals supplied. Bonded deposits are the result of the flyash adhering to the sticky layers of sodium and potassium sulphates and bisulphates which are formed by the affinity that sulphur trioxide has for the dust-laden gases. The sulphur trioxide in turn is the result of oxidation of the sulphur dioxide present in the flue gases and this oxidation is accelerated by the catalytic action of the rust layer on boiler and superheater tubes. Choking and corrosion of air heaters are the result of the presence of sulphur trioxide in the flue gases and is due to the great increase in the dewpoint temperature that can result from the presence of very small quantities of sulphur trioxide. There does not appear to be any complete solution to these problems. Experiments have been made with superheater tubes and air heater

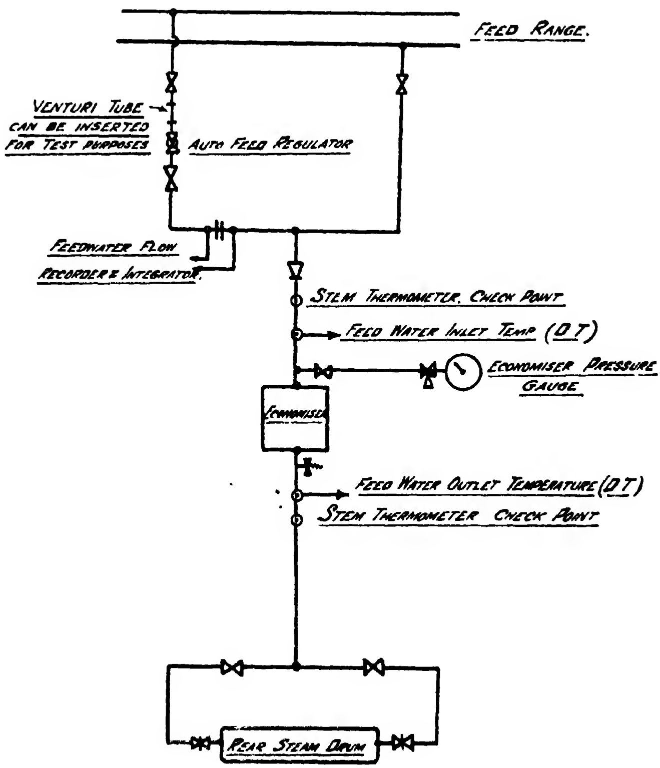


FIG. 205. Points of Measurement in Boiler Feed Pipework.

elements, protected by a film of aluminium and by coating with lime slurry.

INSTRUMENTS

The instruments for boiler house service are now receiving much more attention and rival the indicating and recording equipment usually associated with the electrical control room.

Feed Water Supply. The instruments in this system comprise feed water flow recorders and integrators, both being operated from the same venturi tube or pressure difference device. Feed water inlet and outlet temperatures (economiser) from common temperature indicator (electric resistance thermometer), and pressure gauge (economiser inlet) (Fig. 205).

Other instruments associated with feed water are :—

Dissolved oxygen recorder to check on possible boiler corrosion,

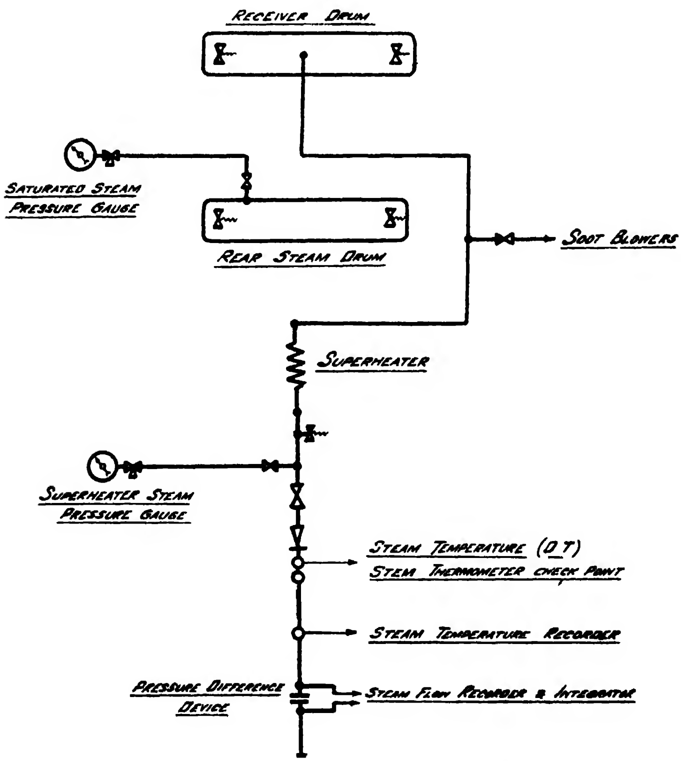
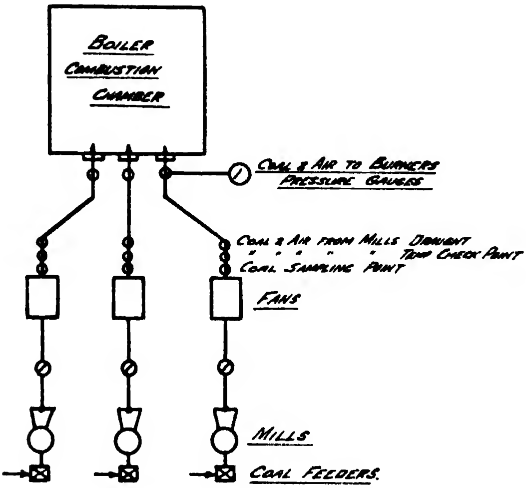


FIG. 206. Points of Measurement in Boiler Steam Pipework.

salinometer and perhaps a pH meter. The oxygen recorder is dealt with under turbine instruments.

Steam Supply. Steam flow indicator, and steam flow/air flow indicator, both operated from same pressure difference device, temperature recorders and temperature indicators (electric resistance thermometer), pressure gauges for saturated and superheated steam ; sometimes a steam flow recorder and integrator is used (Fig. 206).



(1) 156° to 160° F. (1) Normal load.
(2) 140° to 155° F. (2) Maximum continuous load.

FIG. 207. Points of Measurement in Boiler Coal and Air Pipework.

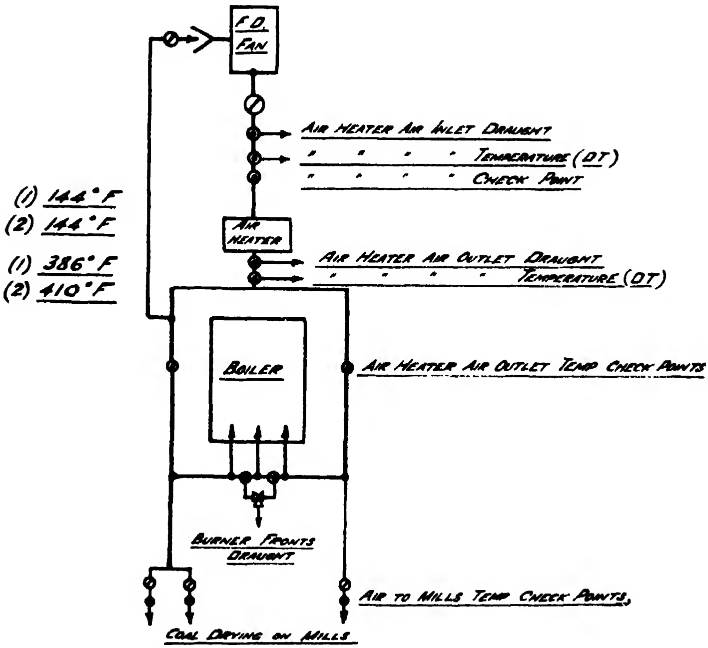
Fuel Supply. The weighing of coal is a fundamental measurement and the more accurately it is effected the more confidence will there be placed in the station returns. The importance of weighing coal correctly will be appreciated when it is understood that the boiler house efficiency is wholly dependent upon correct returns. To weigh coal correctly is a much more difficult problem than is generally realised and a considerable error in stock can be easily made unless care is exercised.

The measuring of the coal put into a boiler may be by independent weighing machines in the down chutes from the bunker to the stoker or mills. Coal meters fitted on stokers give the total quantity of coal supplied to the grates, also the rate per hour at which this is supplied.

In pulverised fuel plants a sampling point (Fig. 207) may be

included in the fuel pipe. The safe storage of pulverised fuel or small coal in bunkers is facilitated by level indicator, lamps or audible alarms indicating a bunker running empty or full.

Air Supply. Draught gauges, temperature indicators (electric resistance thermometer), temperature recorders, and air flow indicators and recorders are usual (Fig. 208). Nitrogen gas actuated temperature recorders are also used for air and flue gas temperatures.



(1) Normal load.
(2) Maximum continuous load.

FIG. 208. Points of Measurement in Boiler Air Circuit.

Flue Gases. Draught gauges, temperature indicators, temperature recorders, CO_2 indicators and recorders (Fig. 209), are usual and CO meters and smoke density meters may be included.

Considerable variations in gas temperatures may be obtained at different points of a duct, air heater or economiser and check points for mercury in glass thermometers should be provided.

A fall of CO_2 percentage does not always imply too much air, it may be due to insufficient air. When this occurs combustion is incomplete and part of the carbon turns to CO instead of CO_2

giving out only about one-third of its available heat. An electrical CO meter permits correction of this fault

Draught gauges give an indication of the balance of draught throughout the boiler and the tightness of the baffles and brickwork.

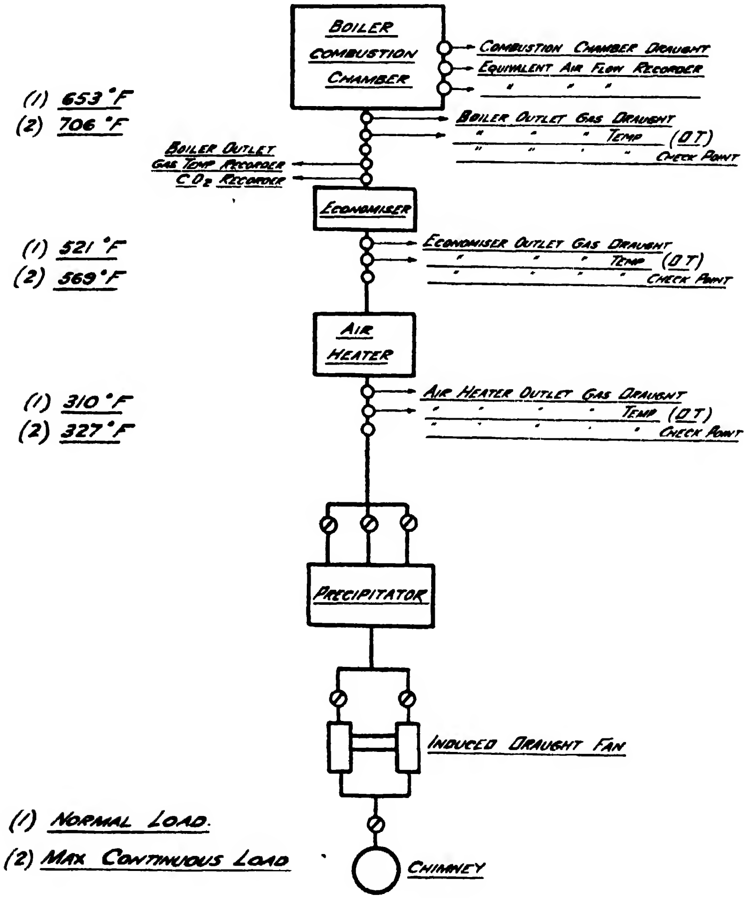


FIG. 209. Points of Measurement in Boiler Gas Circuit.

The CO_2 indicator or recorder indicates the efficiency of combustion, too low a reading usually implying excess air, and too high a reading, insufficient air. The presence of CO is an indication of incomplete combustion, often due to insufficient air.

A typical list of instruments and points of measurements for a large boiler is given.

12 in. pressure gauge (superheated steam). Boiler side of stop valve.
12 in. pressure gauge (saturated steam). Rear steam drum.
Nine-point draught indicator.

Pressure under grate L.H.
,, ,, ,, R.H.
Combustion chamber L.H.
,, ,, R.H.
Boiler exit (two-way cock L.H. and R.H.).
Economiser exit (two-way cock L.H. and R.H.).

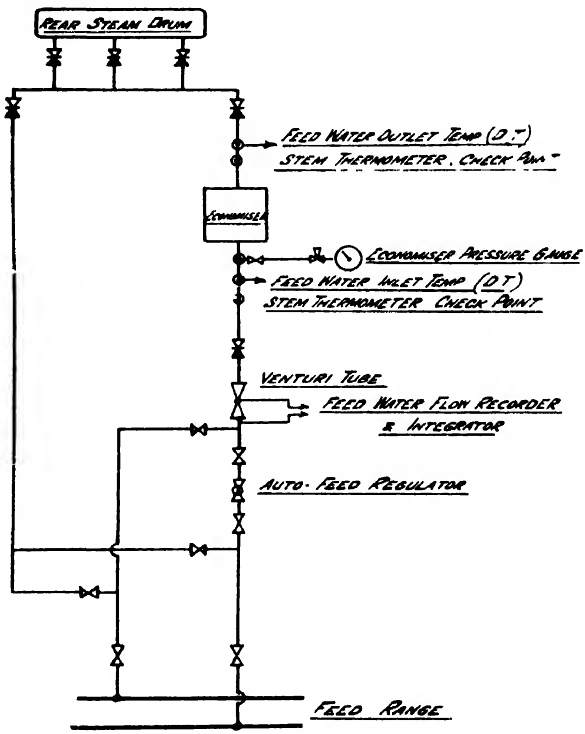


FIG. 210. Points of Measurement in Boiler Feed Pipework.

Air heater gas exit L.H.
,, ,, ,, R.H.
Secondary air pressure (two-way cock L.H. and R.H.).

12 in. feed flow recorder and 6 in. feed flow integrator.
Venturi tube on economiser feed piping.

12 in. steam flow indicator.
Pressure difference device in steam main.

10 in. CO_2 indicator, 12 in. CO_2 recorder.
Economiser outlet.

Steam flow/air flow indicator.
Steam main and gas ducts.

The latter is two meters in one, a steam flow meter operated by the differential pressure across an orifice plate in the main steam pipe, and the air flow meter which is actuated by the differential pressure between the first and last pass of the boiler (or in the gas ducts), this varying in proportion to the flow of air.

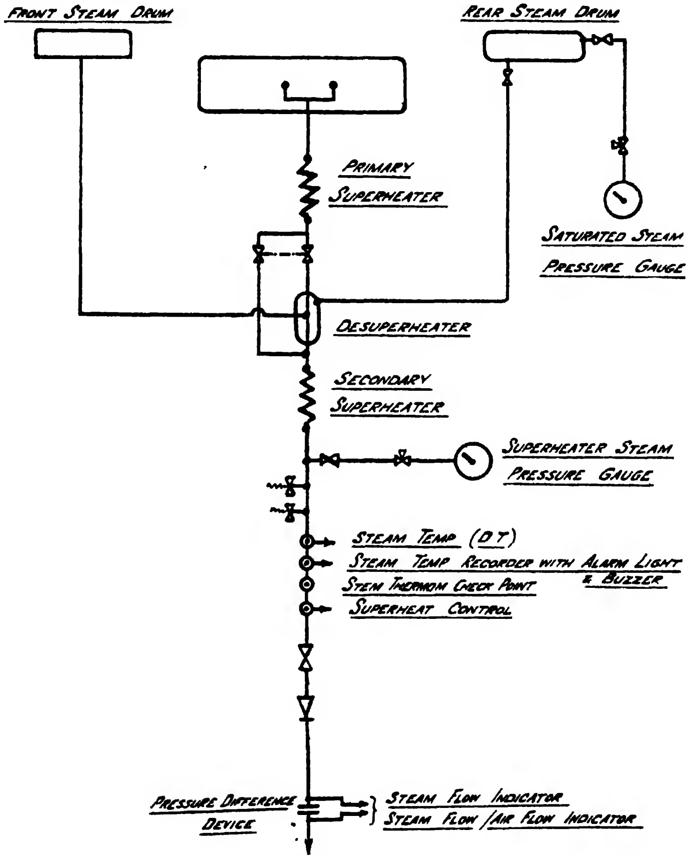


FIG. 211. Points of Measurement in Boiler Steam Pipework.

12 in. Duo air temperature recorder.
Air to grates L.H. and R.H.
12 in. steam temperature recorder.
Boiler side of stop valve.
Twenty-point temperature indicator.
Steam before stop valve.
Gases leaving boiler L.H.
„ „ „ R.H.
„ „ economiser L.H.

Gases leaving economiser R.H.
,, ,, air-heater L.H.
,, ,, ,, R.H.
Air entering ,, L.H.
,, ,, ,, R.H.
,, leaving ,, L.H.
,, ,, ,, R.H.

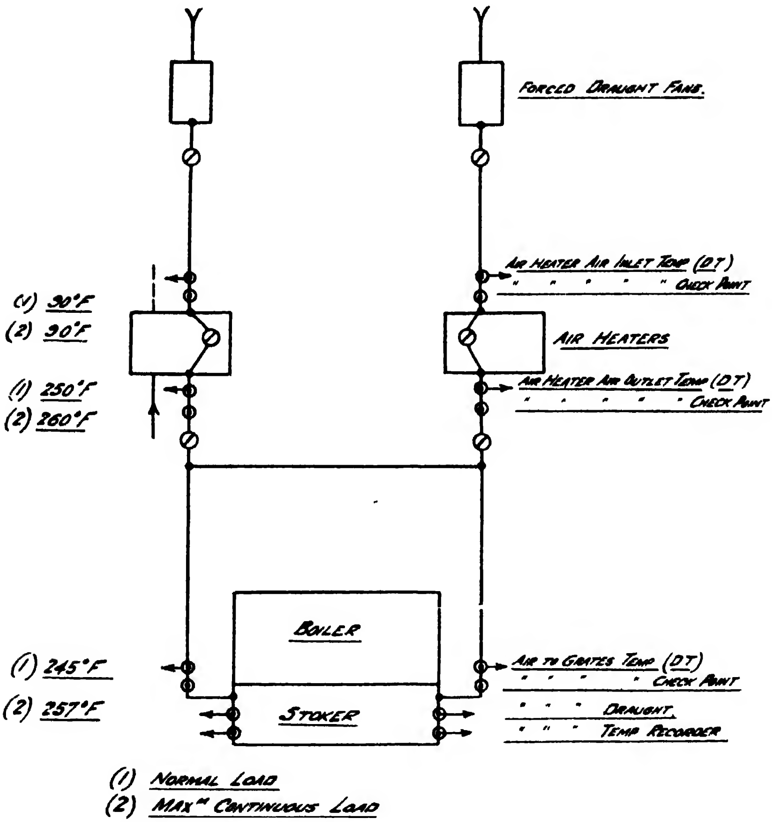


Fig. 212. Points of Measurement in Boiler Air Circuit.

Air entering secondary air nozzles L.H.
,, ,, ,, ,, ,, R.H.
,, under grates L.H.
,, ,, ,, R.H.
Water entering economiser.
,, leaving ,,
12 in. pressure gauge feed water.
Inlet to economiser.

The points of measurement are indicated on Figs. 210 to 213.

Instrument Panels. The best position for boiler instrument panels appears to be the firing or operating floor.

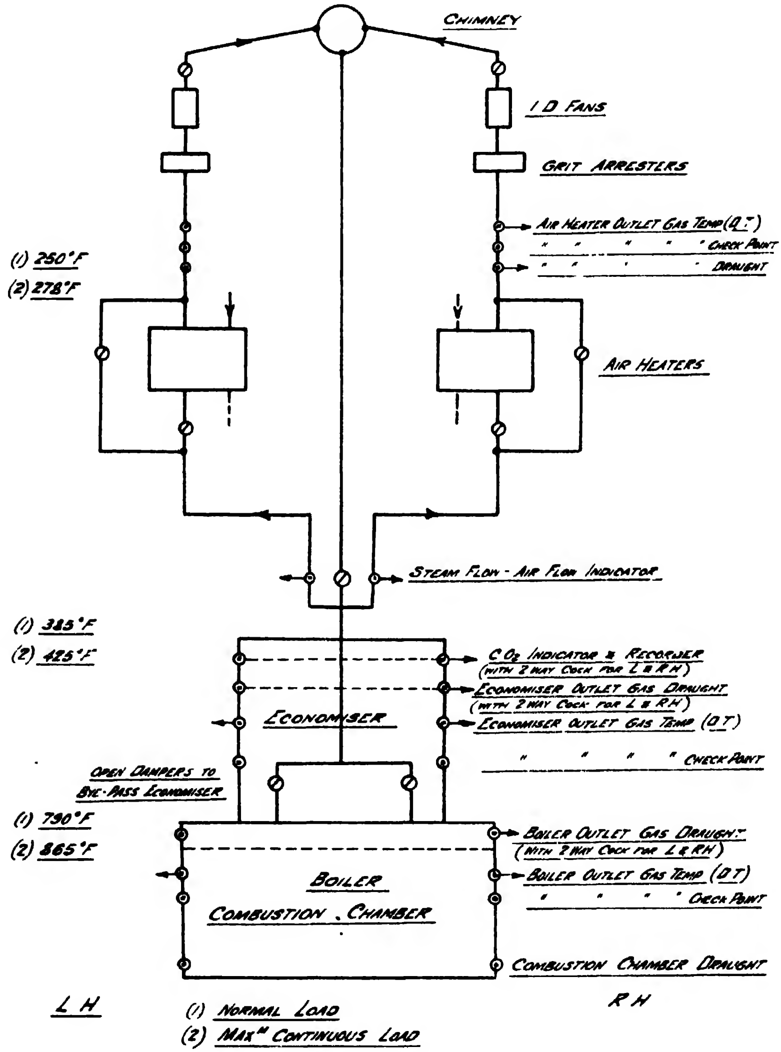


FIG. 213. Points of Measurement in Boiler Gas Circuit.

The position (Fig. 214) depends upon the arrangement of the boilers, and the method of combustion control.

In some cases the panels have been grouped and placed in a separate control room (Fig. 215) in or adjoining the boiler houses.

They can be placed in front of the boiler bunker columns if space is allowed for access. The tubing and cables can enter the panels

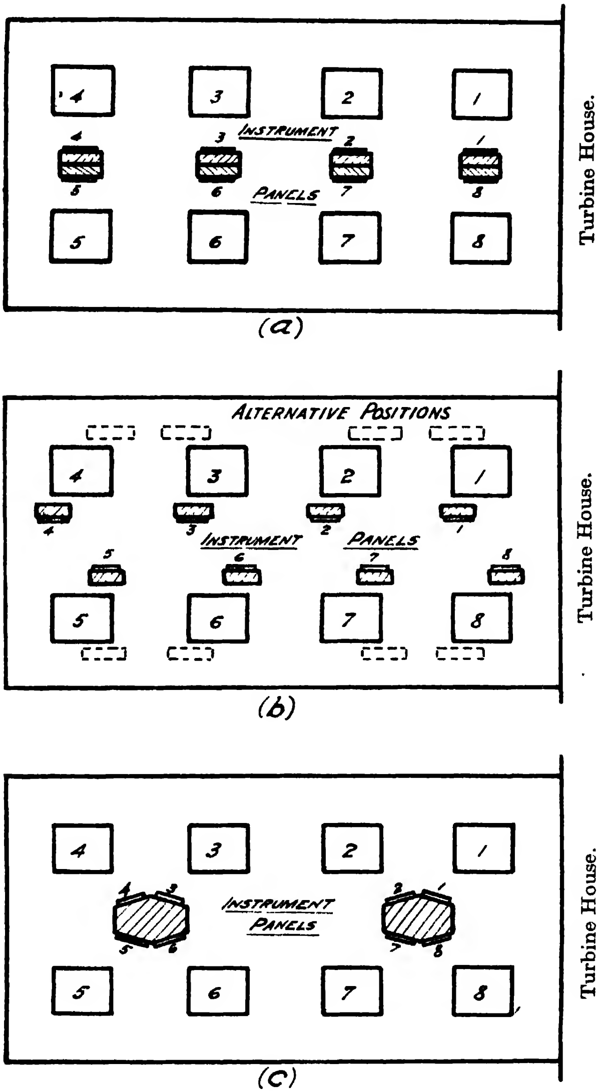


FIG. 214. Alternative Arrangements of Instrument Panels on Boiler Operating Floor.

from beneath the floor and be taken direct to their respective instruments and controls. The design and arrangement of the

panels and instruments are important ; what may appear to be an ideal layout on paper may in practice fall short of expectations. A panel can be made of steel plate and angle framing having an enamel finish (Fig. 216). The panels should be dustproof, holes in the floor for the tubing and cables being sealed, particularly where a dusty basement is directly below. Whether the panels are arranged in cubicles of rectangular or triangular formation, it is an advantage to provide an access door at each end. Although the triangular formation has the advantages of reduced floor space, better appearance and easier control of a number of boiler units from a central position, there is a tendency for the operator to look at the instruments from an angular position. The latter may give rise to inconvenience unless the illumination is suitable for each type of instrument.

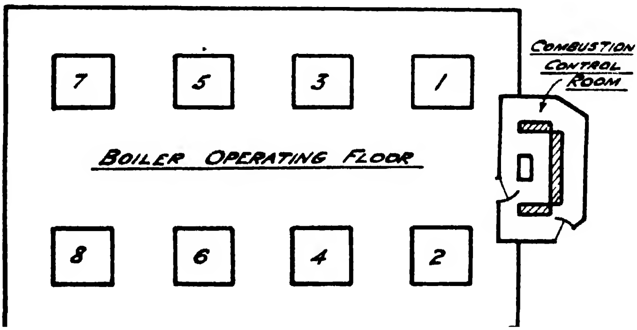


Fig. 215. Combustion Control Room adjoining Boiler House.

The instruments should be so arranged that they can easily be seen and selected at will. From the point of view of keeping check on the operating conditions of the plant, only essential instruments should be included. If too many records or readings are obtained considerable time and qualified staff are required to compute results. Unnecessary markings on the scales should be omitted, and the nameplates designating the various instruments and points of measurement, etc., should be plain but conspicuous. Open scales are preferable to cramped scales as the operators can see at a glance the gauge or chart readings.

The projecting types have largely been superseded by the flush mounted type. This type enables the instruments to be arranged to best advantage on the panels, and the appearance of the panels and instruments is improved. The remote control switches and ammeters for the draught plant motors can also be mounted on the

panels. The lower portion of the panel is probably the best position for the electrical apparatus can be grouped and kept apart from the other equipment.

The positions of entry and exit of the tubing and cables should,

FIG. 216. Boiler Control Panel, Battersea Power Station.

if at all possible, be available early in the plant construction period, so that provision can be made, thus avoiding unnecessary cutting later.

Good general lighting is used and appears to have given satisfaction. Probably the ideal method, although not so simple to apply, would be to light the instruments individually. Low voltage lamps of relatively high wattage are suitable and a transformer would supply the current at the desired voltage.

It is advisable to provide emergency lighting and an independent circuit fed from the station battery is the usual arrangement.

The following instruments are mounted on the panels :—

Saturated steam pressure gauge.
Superheated ,, ,, ,,
Economiser pressure gauge.
Draught indicator.
Feed water flow recorder.
,, ,, ,, integrator.
Steam flow indicator.
Steam flow/air flow indicator.
Distance temperature indicator.
CO_2 indicator and recorder.
Superheater control apparatus.
Remote master controllers for induced and forced draught fan motors.

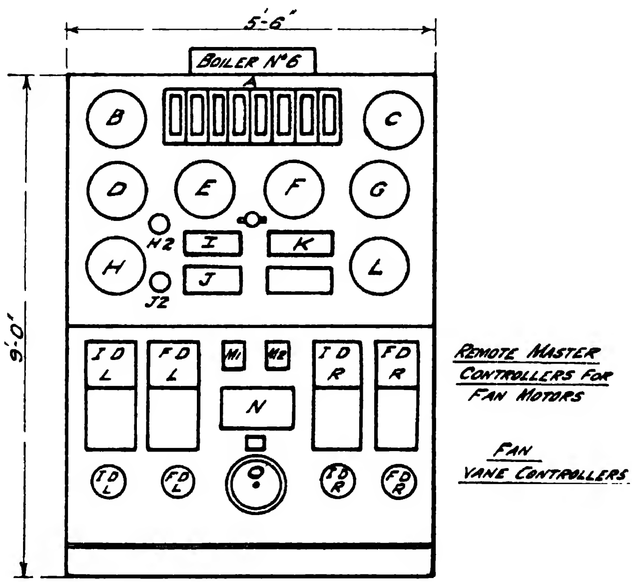


FIG. 217. Typical Boiler Instrument Panel.

A—Multi-point draught and pressure gauge.
B—Superheated steam pressure gauge.
C—Saturated steam pressure gauge.
D—Steam flow indicator.
E—CO_2 recorder.
F—Two pen air temperature recorder.
G—Feed water flow integrator.
H—Steam temperature indicator (H2—alarm lamp).
I—CO_2 indicator.
J—Steam flow/air flow indicator (J2—adjustment).
K—Multi-point temperature indicator and switch.
L—Feed water flow recorder.
M1 and M2—Switches with double pilot lights } Superheat control.
N—Steam temperature controller
O—Remote control.

Feeder motor starters (pulverised fuel units).
Vane or damper control units for induced and forced draught fans.

The ammeters for the secondary air fan and stoker motors can also be mounted on the panels but this is not essential and it may be better to fit them to their individual starters.

Automatic Boiler Control. This is generally considered to be most advantageous where the load on the boiler plant is subject to frequent variations and/or where it is essential to maintain a constant steam pressure.

In a base-load station such control is of great assistance in maintaining a constant steam pressure, and if superheat control is provided, a constant superheat temperature. A better average station efficiency as compared with manual control should be obtained. A base-load station has a reasonably steady loading for the greater part of a day, but it is still necessary to raise and lower load at given times, and automatic control enables the boiler plant to be maintained at the best possible efficiency during these periods. Automatic control will generally result in an improved steam pressure line and a higher average boiler efficiency with a justifiable saving in fuel.

In secondary stations it is perhaps of greater benefit due to the more frequent load changes (see also Chapter XVII, Vol. 2).

Boiler Performance Data. The data given in Tables 32 to 37 are included for the purpose of comparison only, as the conditions of operation together with the circumstances obtaining will greatly affect the performance and costs. Further data are given in Volume II.

TABLE 32. *General Data*

Type of Boiler	Chain Grate Stoker	
Actual evaporation lb./hr.	150,000 N.E.R.	187,500 M.C.R.
Equiv. evaporation from and at 212° F. lb./hr.	188,250	235,313
Factor of evaporation	1·25	1·25
Steam pressure at superheater outlet, p.s.i.	625	625
Steam temp. at superheater outlet, °F.	850	850
Pressure drop through superheater, p.s.i.	26	40
Water temp. at economiser inlet, °F.	250	250
Water temp. at economiser outlet, °F.	360	375
Coal burnt per hour, lb.	18,600	23,500
Coal burnt per sq. ft. of effective grate area per hour, lb.	40	50
Max. heat liberated per cubic ft. of combustion chamber volume. B.Th.U. per hour	19,300	24,200
Total heat input per lb. of steam. B.Th.U.	1,218	1,218
Guaranteed overall efficiency, per cent.	85·5	84·5

TABLE 33. *Heat Losses*

Heat given to steam	per cent.	85·50	84·50
Loss in dry flue gases	,,	4·54	5·16
Loss due to moisture and combustion in hydrogen	,,	4·64	4·69
Loss due to combustion in ash	,,	1·50	2·00
Loss due to radiation	,,	2·20	2·00
Loss unaccounted for	,,	1·62	1·65
Total	,,	100·00	100·00

TABLE 34. *CO_2 Data*

CO_2 in combustion chamber	per cent.	14·00	14·00
CO_2 at boiler exit	,,	13 75	13·75
CO_2 at chimney inlet	,,	12·25	12·25

TABLE 35. *Air and Flue Gas Particulars*

Air at preheater inlet	temperature °F.		90	90
Air at preheater outlet	,,		245	260
Air at stoker inlet	,,		235	250
Gas at boiler outlet	,,		690	775
Gas at economiser outlet	,,		375	415
Gas at preheater outlet	,,		240	270
Air at preheater inlet	pressure in. W.G.		3·0	4·9
Air at preheater outlet	,,	,,	2·0	3·4
Air under grate	,,	,,	1·6	2·8
Gas in combustion chamber	,,	,,	0·1	0·2
Gas at economiser inlet	,,	,,	1·35	2·45
Gas at economiser outlet	,,	,,	2·4	4·2
Gas at preheater outlet	,,	,,	3·6	6·0
Air required at preheater inlet	volume cub. ft./min.		53,400	67,200
Gas at preheater outlet	,,	,,	83,800	109,600

TABLE 36. *Comparative Prices of Boiler Equipment*

Boiler with mountings	54·00
Superheater (with temp. control)	7·20
Economiser	8·20
Stoker	8·50
Air preheaters	4·40
Forced draught plant	3·10
Induced draught plant with grit arrestors	6·60
Chimney (steel)	2·80
Soot blowers	0·90
Instruments	1·40
Auxiliary Switchgear	2·00
Flue dust plant	0·90
Total	100 per cent.

Fig. 218 gives gas volume data.

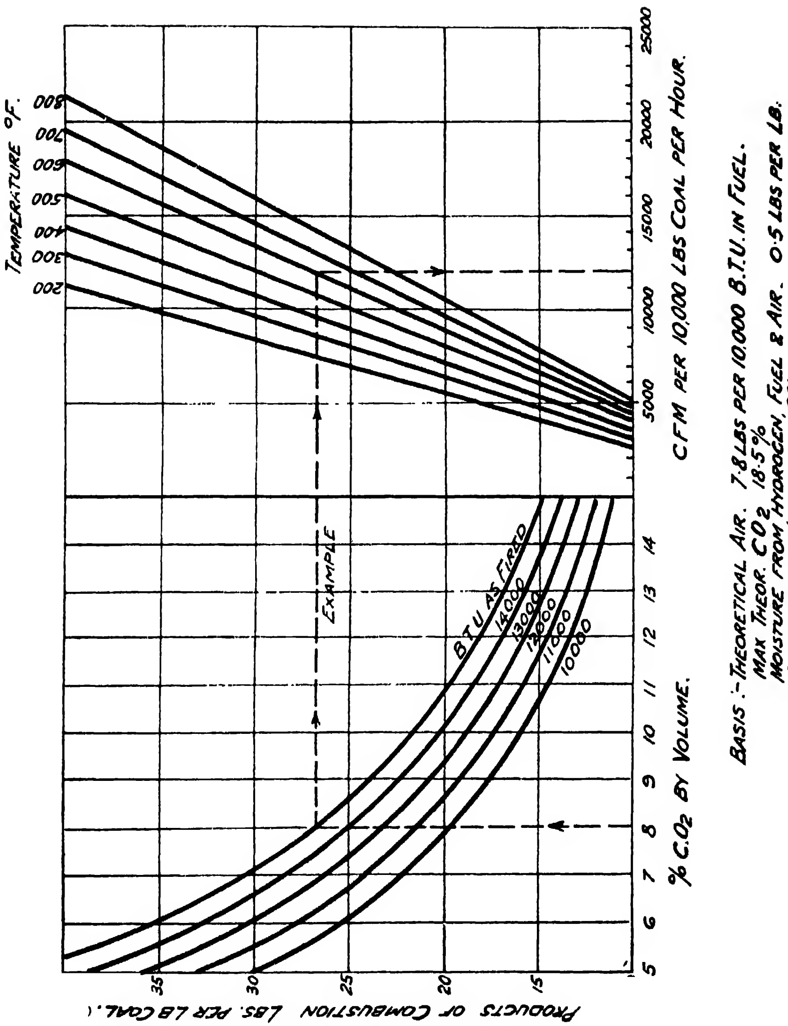


FIG. 218. Gas Volume Chart for Bituminous Coal.

TABLE 37. *Comparative Prices of Boiler Equipment*

Boiler and superheater	45·00
Economiser	9·00
Air heater	9·00
Draught plant	14·00
Stoker	11·00
Chimney, ash, vacuum and plants, soot blowers	10·00
Instruments and controls	2·00
Total	100 per cent.

Pulverised Fuel Data (1935/38).

Hammer Mill (one working year) (Impax.)

Units (kWh.) consumed per ton of coal . . 30
Materials cost per ton of coal. . . . 3·00*d.*
Labour (maintenance) per ton of coal . . 0·45*d.*

Attritor Mill:

Maintenance cost per ton of coal . . . 3·00*d.*
Other costs per ton of coal . . . . 3·50*d.*

Banking Losses.

0·6 cwt. coal per 10,000 lb. of boiler steam capacity. Over 12 hours outage it may be better to burn off and relight.

Auxiliary Power.

Chain Grate Stoker—0·96/0·98 kWh. per 1,000 lb. of steam per hour on test. 1·0/1·4 normal running. Retort Stoker—1·4 on test, 1·7/1·9 normal running. A good average figure for a unit-fired plant is 2 kWh. per 1,000 lb. of steam per hour on test and about 15 per cent. higher for normal running conditions. These are for Roller Mill plants, but for Ball Mills a figure of 2·5 kWh. would be general on test. For Central-fired plants the average figure would possibly be 1·9 to 2 kWh.

CHAPTER VIII

PIPEWORK

THE principles to be followed in all sections of pipework may be summarised as :—

(1) The systems adopted must ensure maximum reliability of the plant served. In certain sections it may be essential to have complete duplication.

(2) It should be possible to carry out inspection and maintenance on any section of plant without the need for complete shut-down.

(3) The pipes for the main steam, feed water, and circulating water systems should be of sufficient size to allow for extensions to the station. The pressure drop is reduced by increasing the pipe sizes, but the cost is greater. The auxiliary plant power in the feed and circulating water systems is also reduced.

(4) The routes chosen should be as direct and simple as possible, keeping in mind the need for an uncrowded layout and isolation from other sections of plant such as switchgear, transformers and cables, etc.

(5) Valves and interconnecting pipes should be as few as possible, but the necessity for sectionalising and load transfer in times of emergency, inspection, or maintenance, should not be overlooked. Valves should be placed and grouped to facilitate operation.

(6) Consideration should be given to the efficient drainage of all pipes although the number of drainage points should be as few as possible consistent with safety. An adequate number of air release valves should be provided throughout the various pipework systems.

(7) Provision should be made for expansion and contraction, and the full benefits of the normal routes made use of to achieve the desired degree of elasticity.

(8) The pipes should be made in the longest possible lengths to reduce the number of joints. Joints and jointing materials should be standardised.

(9) Template pipes should be as few as possible, to reduce erection time.

(10) The use of trenches for the more important services is not recommended. Trenches and chases may be used for the smaller pipes, particularly in the vicinity of the turbines and its auxiliaries. If pipes are placed in an orderly manner they are always in sight and accessible ; a leaky joint or other defect being brought to notice at once. The supports, anchors and joints should all be in accessible positions so that inspection is possible throughout the life of the plant. The anchoring points should be examined at regular intervals to ensure that the fixings are in good order, otherwise undue strains may be imposed on certain joints. When pipes are placed in trenches leaks may go undetected for quite a time, and a trench is liable to become a receptacle for rubbish.

(11) Particular care is necessary in the erection of pipes connecting up to such items of plant as condensers, pumps, etc., to prevent undue strains being put on the branches. Serious damage will result unless special care is taken. In some cases the " closers " should have expansion pieces to give the desired degree of flexibility. Pumps may be pulled out of alignment and require complete re-erection.

Main Steam Pipework. The main steam pipework comprises the pipes running from the isolating valves on the boilers to the turbines *viâ* steam receiver, together with interconnecting pipes which may

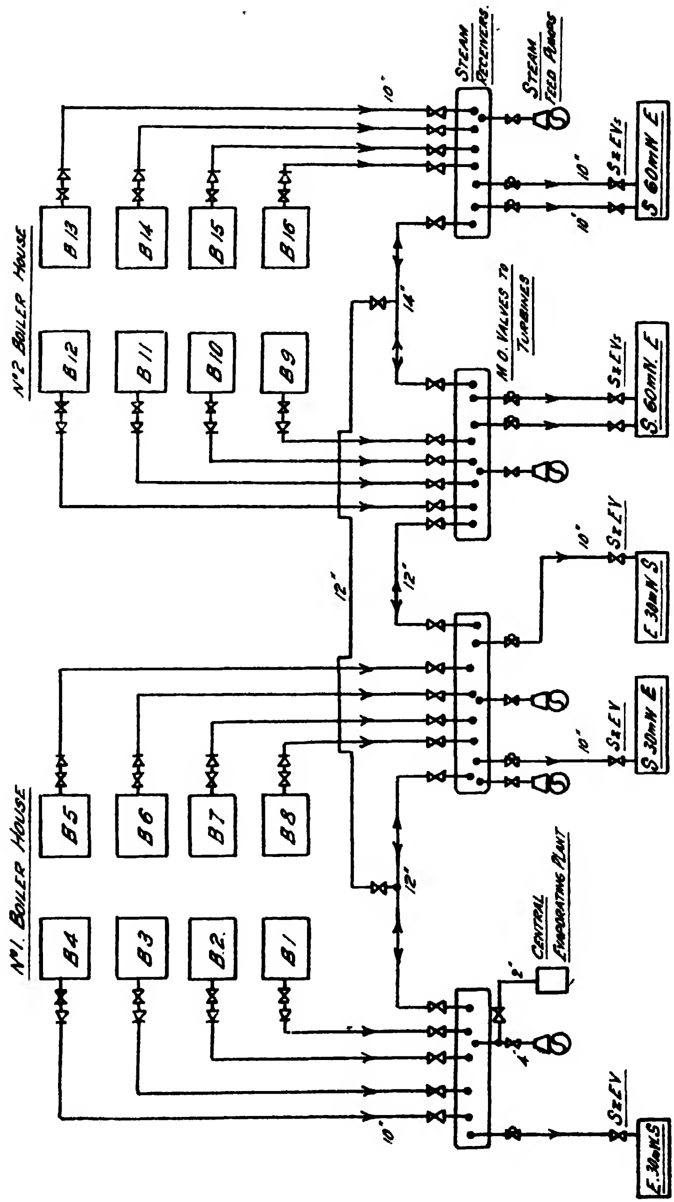


Fig. 219. Steam System for 210 MW Station (Boilers 625 p.s.i., 850° F.).

be included to transfer steam as required. Figs. 219 to 221 show typical schemes. The pipe-work should be run as direct as possible, having regard to appearance and provision for expansion. All piping should be arranged with a gradual fall towards the steam receivers for drainage, and where possible such falls should be in the direction of steam flow. The obvious route will usually provide all that is desired so far as expansion is concerned. If a wire model of each alternative pipeline be made, there will be no difficulty in ascertaining which is the more flexible. In very large boilers—500,000 lb./hr. and over—it is usual to employ multiple steam and feedwater pipes, the purpose of which is to provide greater flexibility

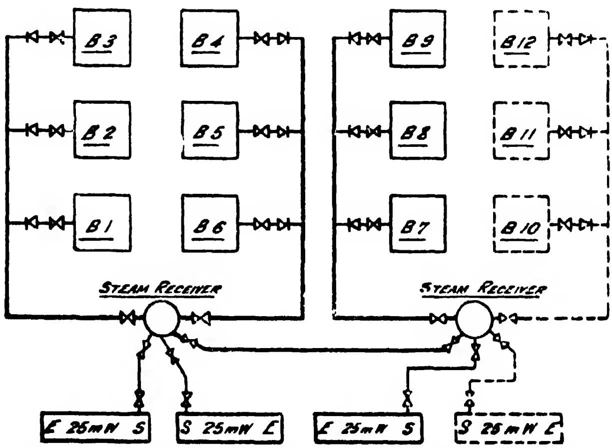


Fig. 220. Steam Pipe System for 100 MW Station (Boilers, 300 p.s.i., 750° F.).

of connection, always a problem with high temperature, high-pressure piping, where the tube thickness is considerable in relation to the tube bore. Certain layouts, however, do present difficulties and are overcome by using expansion loops, corrugated bends or creased bends. The case for the corrugated steam-pipe expansion bends is established where restricted space and low stresses are important. On the other hand, the corrugated pipe has a high friction drop, is costly to construct and is conducive to whistling and vibration at certain steam speeds. The pipes are callipered at the corrugations on the vertical and horizontal axes and if considerable variations are revealed after pipes have been corrugated and bent it may be necessary to reject them unless they can be rectified. Dies are prepared and the faulty corrugations (bad circularity) are in turn pressed back under heat.

The thinning of material due to repeated heatings and workings must be watched and drill tests may be made on similar pipes. A bend of large radius is not so flexible as one of small radius. The advantage of a large radius is that the pipe material is not so highly stressed in bending to a large radius as when the bend is sharp. The ability of a pipe to resist springing depends on its diameter and thickness, but chiefly on the diameter. A pipe run is more flexible if creased pipes are used at bends and the space required is reduced. In order to still further reduce resultant expansion forces, it is advisable to shorten the pipe by about three-quarters

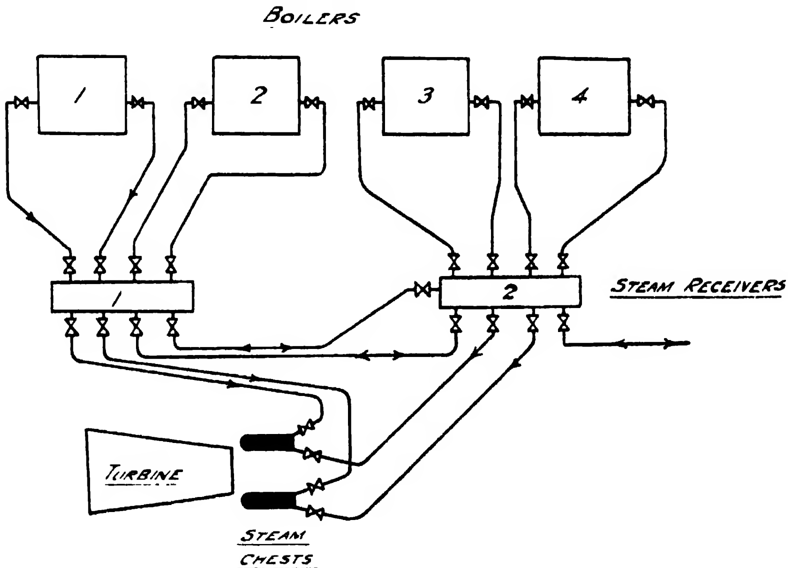


FIG. 221. Steam Pipework for 100 MW Turbine.

of the calculated amount of expansion, and to stretch the pipe when it is being put into place cold.

For a temperature of 850° F. the expansion would approach $7\frac{1}{2}$ in. per 100 ft. Piping withstands a much greater strain when cold, and the pipe lengths are reduced by a predetermined amount. The pipe lengths are then pulled up on erection by an amount varying from 50 to 100 per cent. of the total expansion between the anchorages. The actual amount of springing to be taken up cold is dependent on the steam temperature. The cold stress remains constant but the hot stress falls with rise in temperature and the amount of the expansion to be taken up hot and cold is fixed by the ratio between the two permissible stresses. On the other hand a pipe range may be

too flexible, in which case large fluctuations in steam demand may set up vibration. Resonance may be found to coincide with some part of the running plant, and in such cases it is necessary to change the supporting arrangement by either adding to or reducing the number of supporting places to eliminate the trouble. The pipe range should be sufficiently flexible to accommodate itself to the movement caused by expansion of the pipes without throwing undue strain on any section or fittings connected thereto. Steam pipe connections to a turbine should be flexible so that small movements do not generate large forces. The main steam piping is made from hot finished solid drawn mild steel tubing.

For 300 p.s.i., 750° F. .	Tensile strength 20 to 30 tons per square inch. (Atmospheric temperature.)
For 625 p.s.i., 850° F. .	Tensile strength 28 to 30 tons per square inch. (Atmospheric temperature.)

In determining the thickness of the pipes cold springing should be taken into account. The thickness should be such that the maximum total stress in the pipes due to a combination of stresses resulting from internal pressure, bending and torsion should be within safe limits.

The thickness of the pipes may be estimated from the following formula :—

$$t = \frac{pd}{2f} + 0{\cdot}1$$

Where t = minimum thickness in inches.
d = outside diameter of pipe in inches.
p = internal pressure in p.s.i.
f = allowable hoop stress in p.s.i.

With the temperature °F.	600°,	700°,	800°,	900°
f	10,000,	8,400,	7,500,	6,500

The tube makers tolerance is added to the thickness given by this formula, and a further addition should also be made for bent pipes to allow for thinning at the back of the bend.

The question of the proper diameter of piping for a given flow of steam is one which has not been solved with great accuracy. The energy loss is not important, but the pressure drop between the boilers and the turbines should be known as accurately as possible.

The chief factor governing the bore of the piping is the allowable pressure head required to overcome the frictional resistance to flow.

The pressure drop is fixed by the steam pressure at the outlet of the superheater and the steam pressure required at the stop valve of the turbine. These facts being known, together with that of the layout, the pipework designer can then select the most suitable pipe bores throughout the range.

The correct diameter for any pipeline is the one which gives the lowest cost per annum when due allowance is made for capital charges and pressure and temperature losses. This diameter, however, may have to be increased in order that the operation of the plant be not seriously interfered with under certain limiting conditions.

The modified Babcock formula gives results which are rather on the high side, but serves as a guide :—

$$P = 0{\cdot}000132 \left(1 + \frac{3{\cdot}6}{D}\right) \cdot \frac{W^2 L . V .}{D^5}$$

Where P = pressure drop in p.s.i.
W = weight of steam in lb. per minute.
V = specific volume of steam in cubic feet per lb.
D = internal diameter of pipe in inches.
L = " Equivalent " length of pipe in feet.

It has been suggested that the pressure at the turbine stop-valve should be given as the boiler blow-off pressure, less a margin of, say, 10 lb. for working tolerance, less the calculated friction drop in the pipeline with maximum load conditions. In the case of auxiliary turbines, these should be provided for operation at reduced pressures, and the inlet and exhaust pipe sizes should be based on the lowest pressure maximum load conditions.

The question of steam velocities does not call for any great comment although very high velocities may cause erosion. Some figures relating to one station are given :—

Working Pressure 300 *p.s.i. and* 750° *F. Specific Volume* 2·205 *cubic ft.*

	Quantity of Steam lb. per hour.	Pressure Drop lb. per sq. inch.	Velocity ft. per sec.
Superheater outlet to steam receiver (10 in. bore)	110,000	4	124
	130,000	6	147
Steam receiver to turbine stop valve (14 in. bore)	240,000	5	137
	300,000	7	172
Total drop from superheater outlet to turbine stop valve	240,000	9 maximum	
	300,000	13 maximum	

Other data are: Boiler 180,000 lb. per hour (650 p.s.i., 850° F.): 12 in. nominal dia. pipe, 13⅜ in. o/dia., $\frac{29}{32}$ in. thick, 11$\frac{9}{16}$ in. actual bore. Velocity 77 ft. per sec.; 4 p.s.i. drop to steam receiver and 7·3 p.s.i. drop from receiver to turbine. Boiler 180,000 lb. per hour: 10 in. nominal dia. pipe, 11½ in. o/dia., $\frac{13}{16}$ in. thick, 9⅞ in. actual bore. Velocity 105·5 ft. per sec.; 8 p.s.i. to receiver and 7·3 to turbine.

One authority has given the following as typical in design :—

Superheated steam . . .	100 to 200 ft. per second.
Dry saturated steam . . .	80 to 160 ,, ,,
Wet steam.	Up to 80 ,, ,,

Other figures are :—

625 p.s.i.	100 to 120 ft. per second.
900 ,, ...	60 to 80 ,, ,,
1,400 ,, ...	40 to 60 ,, ,,

The generally accepted standard appears to be :

25 p.s.i. and 15° F—600 lb., 850°F.
50 p.s.i. and 25° F.—900 lb., 900° F.

The 25° F. temperature drop is considered to be rather liberal and an allowance more in keeping with the actual temperature drop which occurs on a well-lagged system would provide some increase in the design stresses. The permitted pressure drops are thought to be too low and a higher steam velocity would be economically justified.

Air cocks should be provided to release air when charging the ranges.

Extreme temperature differences, such as caused by water draining from pipes into a receiver, may result in fatigue of metal.

Corrosion fatigue is possibly caused by the intermittent presence or impingement of water while a pipe or receiver is under full temperature. Cracks in some cases may be due to overstressing of the metal. The number of temperature cycles to which pipes are subject may also have some effect. Corrosion fatigue in steam pipes receivers and desuperheaters can result from thermal stressing; tensile stresses as high as 20 tons p.s.i. can obtain if impinging water lowers the temperature of a small area of water 200° F. below that maintained by the steam at adjoining areas. With ordinary 24/28 ton tensile pipe material the allowable maximum working stress should be kept below 6,000 p.s.i. if 800–850° F. is the temperature range, and keeping in mind the effects of reversible compound stresses during operating conditions.

Steam Receivers. The present day receiver is a distributing chamber supplied with steam from two, three or more boilers and serving one turbine. Arrangements can be made for interconnecting all receivers by crossover piping to provide for transfer of steam. They should be of adequate size to permit of internal inspection, the overall length depending on the number and sizes of branches. A manhole should be fitted at one end and have a pressed steel hinged cover secured by steel dogs and bolts. In some recent plants the steam receivers are just sufficiently large to take the valves required but do not afford access for inspection in the generally accepted sense. So far as can be ascertained no troubles have been experienced from noise and whistling due to the quick changes of steam flow.

Spherical and longitudinal receivers are in use, although the latter appears to be most favoured.

Horizontal and vertical receivers are in use and the latter type has several advantages :—

(1) In the horizontal receiver all the pipe branches are arranged in a row, which gives the maximum length to the receiver, whereas in the vertical receiver they are " staggered " all round the circumference, and this shortens the receiver.

(2) Water lying in a horizontal receiver may tend to buckle it and start joints leaking, whereas in the vertical type this trouble is avoided.

(3) Pipes being horizontal (or nearly so), valve spindles can easily be extended upwards through the floor above, and neatly arranged on floor stands, thus protecting the operator from accidental steam discharge.

(4) Basement floor space is saved as the vertical receiver is better mounted just under the turbine or boiler house floor and clear of anyone walking below, whereas the horizontal receiver requires to be low down in order to allow of easy steam pipe bends. Site conditions and plant layout will have to be considered for each installation.

The construction will depend primarily on the steam pressure and temperature. Riveted construction may be used for pressure up to 350 p.s.i. and 750° F. although welded plate construction is often used. For pressures of 650 p.s.i. and temperatures of 850° F. solid forged and fusion-welded receivers are used. The solid forged construction is expensive, but is sound and reliable. Fusion-welded receivers are not so expensive and have proved satisfactory for high pressure working. Small cast steel receivers have also been used.

The securing of the branches to the receiver is important. One method is to weld the branches into the receiver body and as a further precaution they are secured by screwing on a plate in nut

fashion as shown in Fig. 222. This additional mechanical fixing inside the body ensures that the strength of a branch is not dependent on the weld alone.

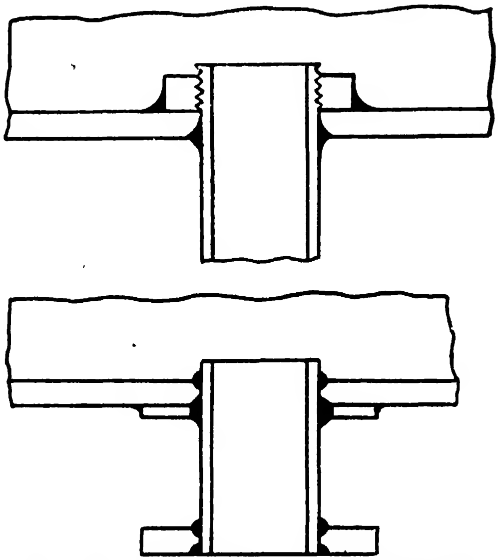


FIG. 222. Steam Receiver Branch Connections.

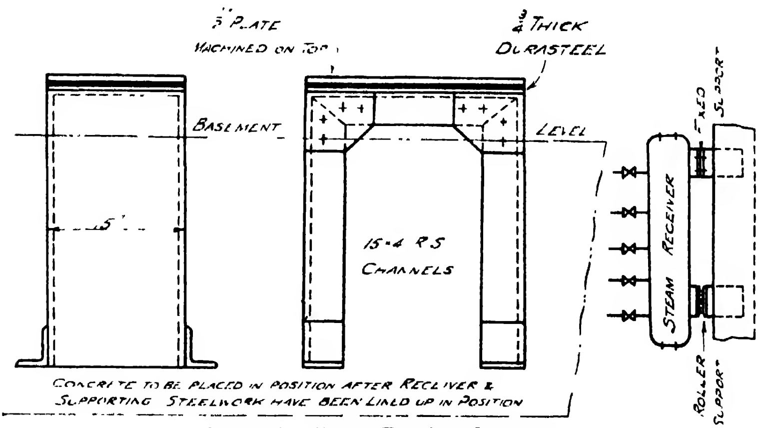


FIG. 223. Steam Receiver Supports.

Steam receivers are manufactured from acid steel having a tensile strength at atmospheric temperature of 28 to 32 tons per square inch. The supporting of the receiver may be by steel channels or alternatively by concrete plinth. The latter method is not ideal,

since the heat transmitted to the plinth affects the concrete and in due course it disintegrates. Special heat-resisting concrete has been tried without success. Steel channel supports with asbestos-steel insulation between the supports and top plates on which the receiver feet are fixed is satisfactory. Cast-iron supports on steel channels are also satisfactory. There are two supports on each receiver,

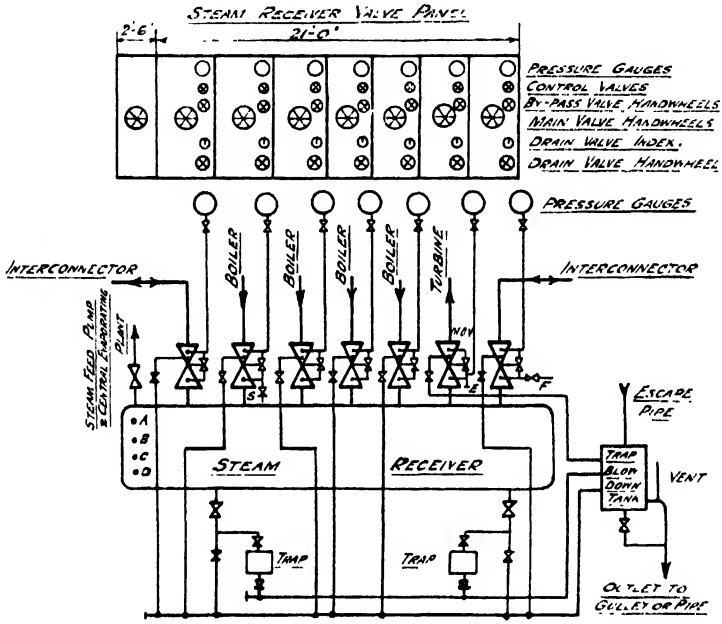


FIG. 224. Steam Receiver and Connections.

A—Stem thermometer.
B—Five-point efficiency recorder (metering panel).
C—Temperature indicator (turbine gauge panel).
D—Distance thermometer (turbine gauge panel).
E—Pressure indicator (control room).
F—Critical pressure gauge.
S—Starting-up connections (pulverised fuel boilers).
M.O.V.—Turbine valve is normally motor operated and controlled from turbine operating floor. The drain valve is normally remote mechanically controlled from a similar position.

one anchored and the other on rollers. Steam receivers may be mounted horizontally or vertically but the former is most usual (Fig. 223).

Provision should be made for automatic and continuous draining as the receiver is a form of separator. The direction of the steam is changed with the result that any moisture present is thrown out. The various connections are indicated in Fig. 224.

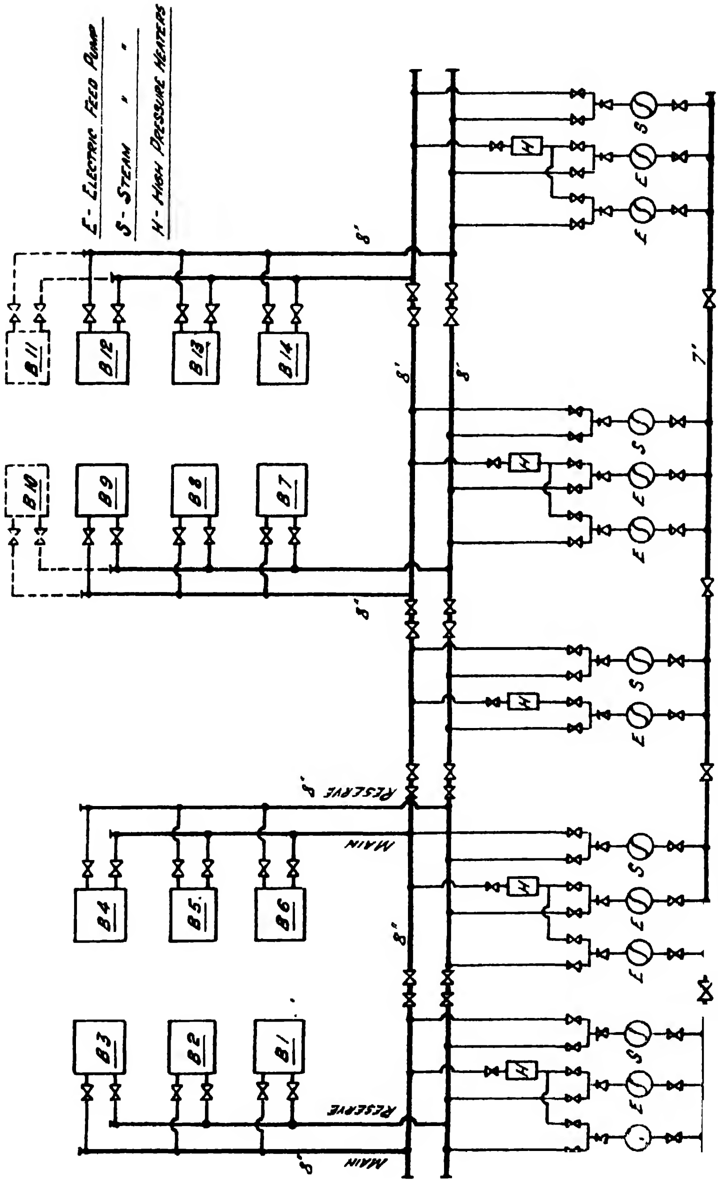


FIG. 2. Feed Water System for 210 MW Station (Boiler Pressure, 625 p.s.i., 850° F.).

Steam Separators. The relative position of the steam receiver to the turbine decides if a separator should be included. If the receiver is placed at a considerable height above the turbine it may

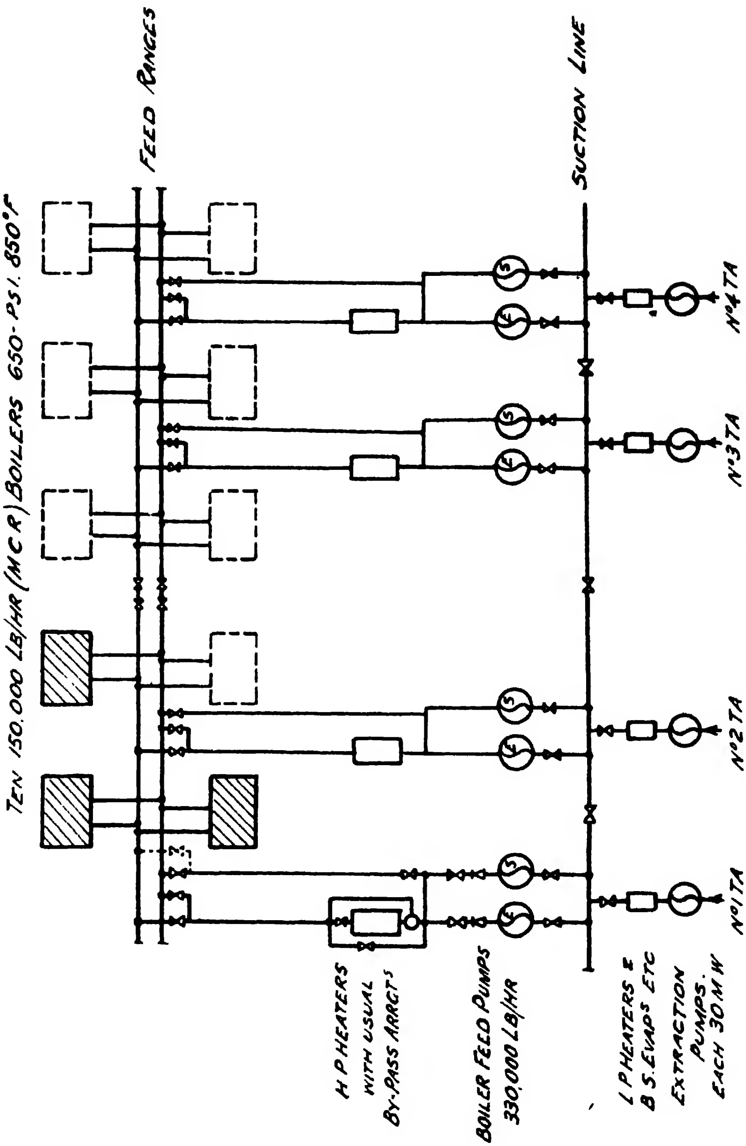


Fig. 226. Feed Water System for 120 MW Station.

be justifiable to include a separator. A separator is similar to an auxiliary steam receiver and usually takes the form of a casting, riveted plate, solid forged or fusion-welded vessel. For high pressure and high temperature working, cast steel solid forged or fusion-welded construction are used.

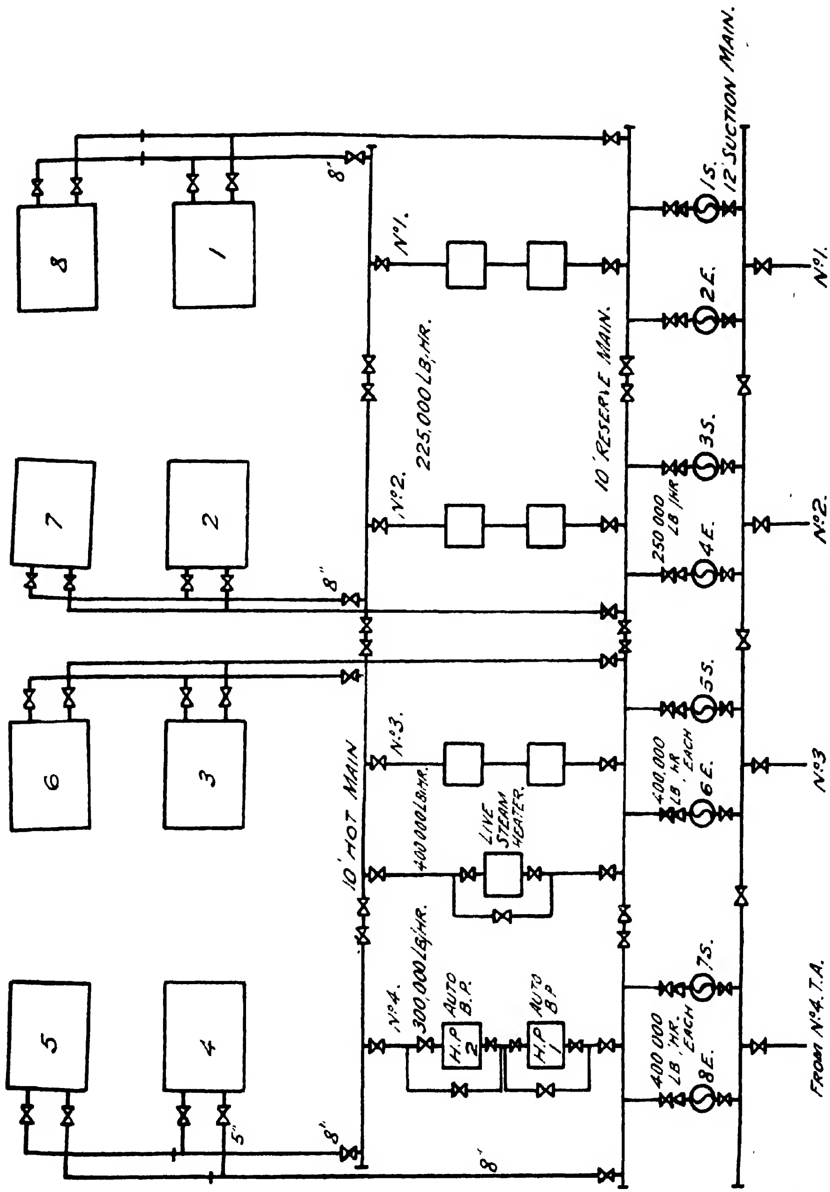


Fig. 227. Alternative Feed Water System.

Main Feed Water Pipework. This commences at the discharge branches of the boiler feed pumps, and terminates at the branches to the individual boilers (Figs. 225 to 228).

The suction feed lines are equally important although not subject to such high pressures under normal working conditions. Relief valves have been fitted in the suction branch to each pump to

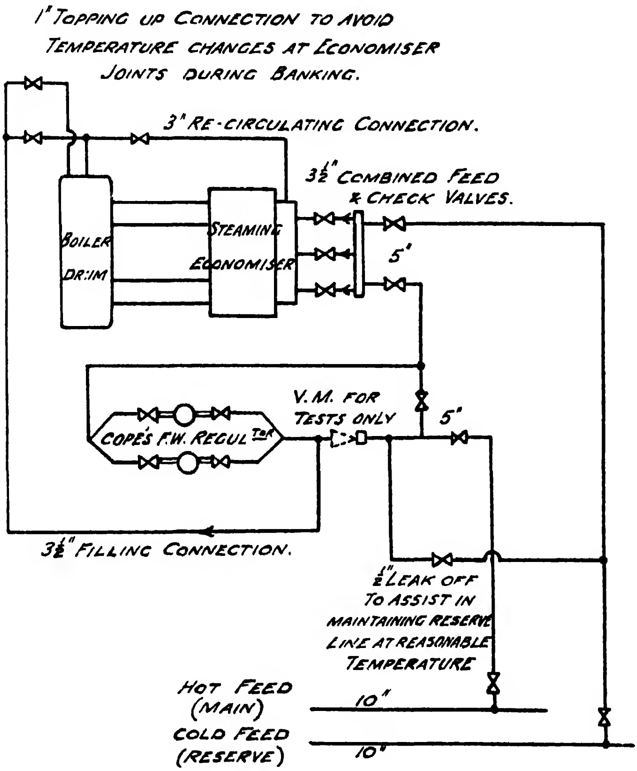


FIG. 228. Feed Water Circuit for 200,000 lb. per hr. Boiler.

release any excess pressure which may be applied, due to a failure of the non-return valve to close when a motor trips, or a leaking valve during shut down periods.

If the suction isolating valve is first closed and the non-return valve fails to close, the former valve and piping between the pump are subject to main range pressure. A 2-in. relief valve has been fitted in the suction pipes of a number of high pressure (650 p.s.i. and over) installations to prevent damage to the suction lines from excess pressure.

The duplicate bus-main is favoured in large stations, although the ring main system with cross-connections has been adopted. Where duplicate mains are installed, one is a standby, and in some cases provision is made (½-in. pipes and valves) to maintain this cold main at a reasonable temperature by leak off and make-up connections. This avoids undue straining of joints should the reserve main be required in an emergency necessitating the sudden flow of high temperature feed water without previous warming (Fig. 228). These leak-off pipes can be misleading, since pressure is still maintained in the lines without a feed water flow.

The unit system is sound in principle but in practice it is better that each unit be interconnected by bus-mains and sectionalising

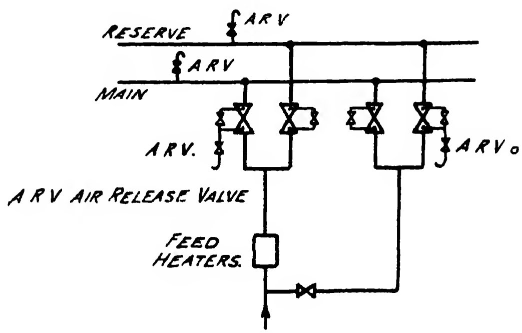


FIG. 229. Feed Range Charging Connections.

valves. This arrangement is more so desirable where boilers are likely to be steaming before a new turbine is available, *e.g.*, during extensions.

With stoker-fired boilers both main and reserve ranges are maintained under pressure so that the operator can make quick change-over to the reserve line in the event of economiser tube failure or other untoward happening. Steaming cannot be continued but a safe water level is maintained. Whatever system is adopted utmost regard must be paid to simplicity, for serious damage may be caused by incorrect valve operation. The by-passing of an economiser may result in the formation of steam with the possibility of water hammer, causing damage to tubes and feed range piping.

The piping material is similar to that used for the main steam piping. The water velocity is kept below 8 ft. per second. Provision should be made for draining all sections, the mains having a gradual fall to the drainage points. Air cocks at the highest

points of the piping system release air when charging the pipes (Fig. 229).

Blow-down and Drain Pipework. This includes all blow-down

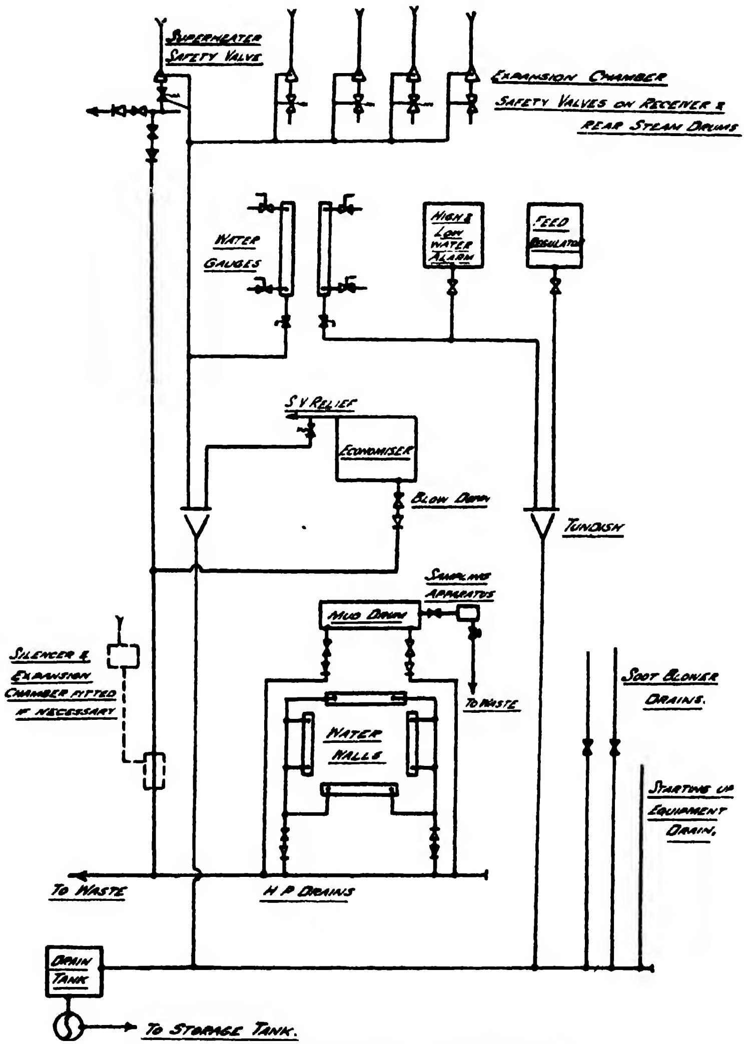


FIG. 230. Boiler Blow-down and Drain Pipework.

and drain services for boilers, turbines, steam receivers, pipe ranges, etc. The pipes should be run as direct as possible and have a continuous fall to the discharge. Figs. 230 to 239 show the usual

boiler drains, etc. The drains associated with the turbine plant are shown under their appropriate sections.

It is desirable that bends be avoided in blow-down ranges to

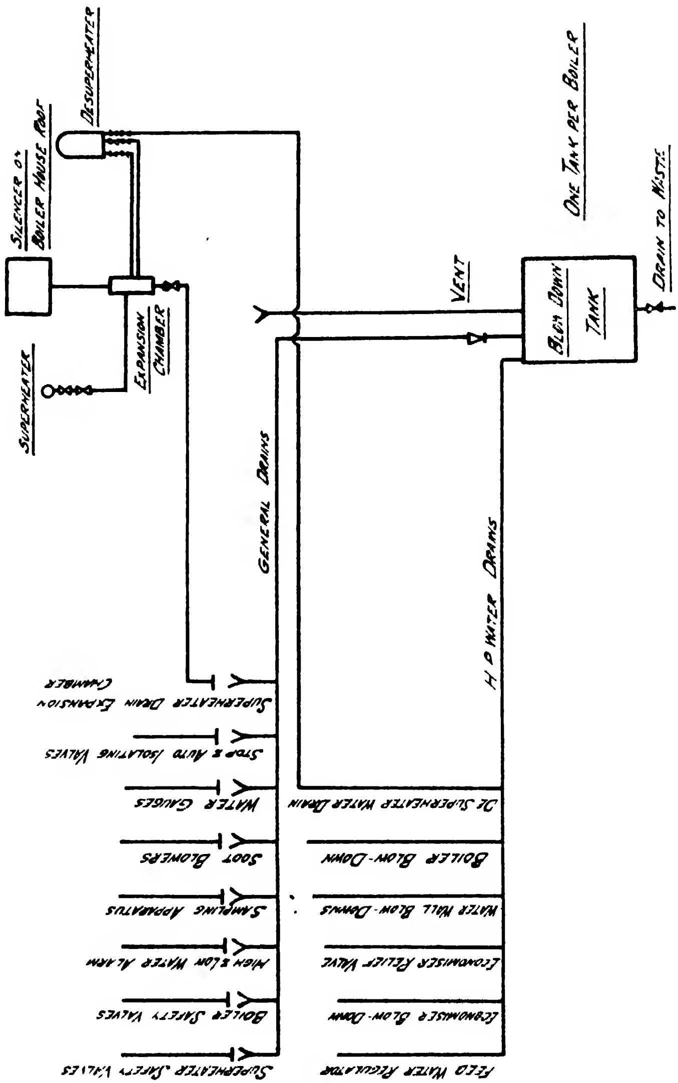


FIG. 231. Boiler Drains

reduce shock due to high velocity water. All piping for the blow-down and drain piping is made from solid hot-drawn mild steel. Tees, bends and special pipes being of cast steel. The length of

piping from the pressure part to the control valve or valves, if two are in series, should be designed for full working pressure.

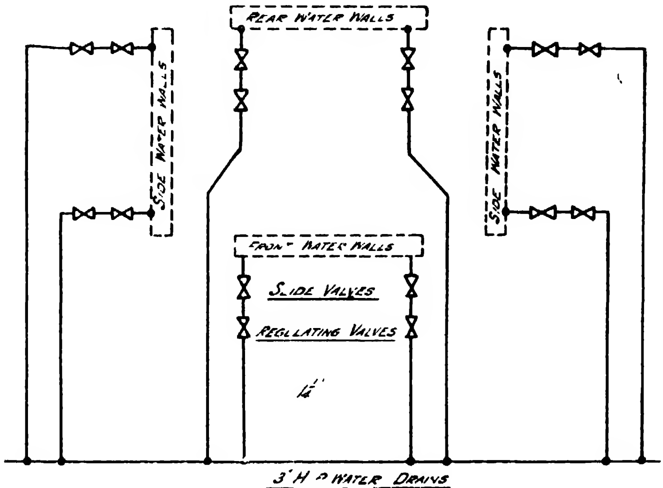


Fig. 232. Water Wall Blow-down Drains.

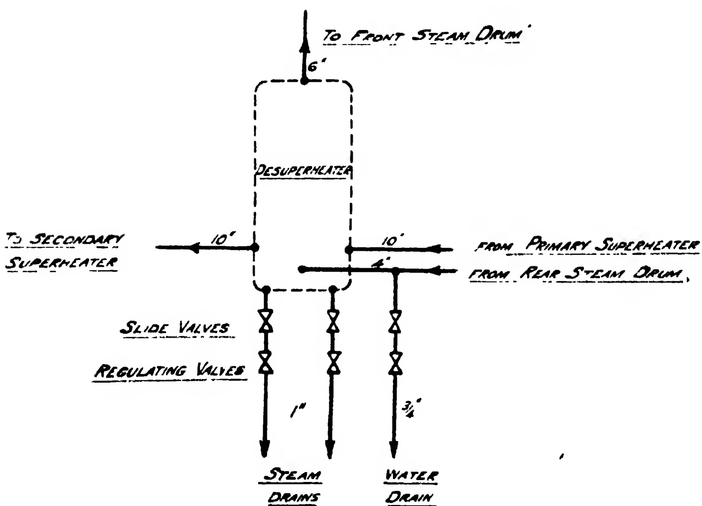


Fig. 233. Desuperheater Drains.

Safety Valve Escape Pipework. With the advent of high-pressure boiler units safety valve escape pipes call for careful consideration in both design and arrangement. The general practice is

for the pipes to be led through the boiler house roof, supporting arrangements being made between the valves and the roof.

The safety valve makes a bend necessary to lead off from the

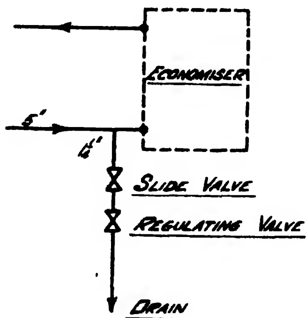


FIG. 234. Economiser Blow-down Drain.

valve to the vertical leg of the escape pipe. This bend should be kept to a minimum radius to limit the reaction on the valve flange when blowing-off. By using cast steel a reasonably small bend may be made. Immediately after the bend the pipe should be run direct

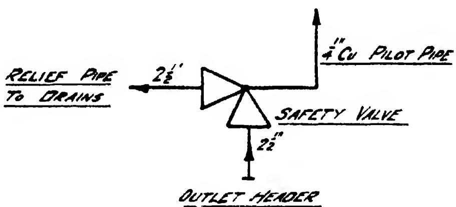


FIG. 235. Economiser Safety Valve.

to an expansion chamber which is really a larger pipe provided with a joint to give the desired flexibility. The plate or joint on the bottom of the expansion chamber should be arranged to provide adequate lateral movement. This loose sealing plate is quite effective in

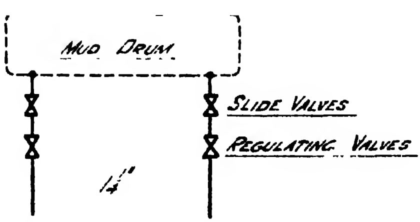


FIG. 236. Blow-down Drains.

preventing excessive steam leakage. The arrangement of safety-valve escape piping should be such that there are no expansion stresses on the valves. The vertical leg of the escape pipe should

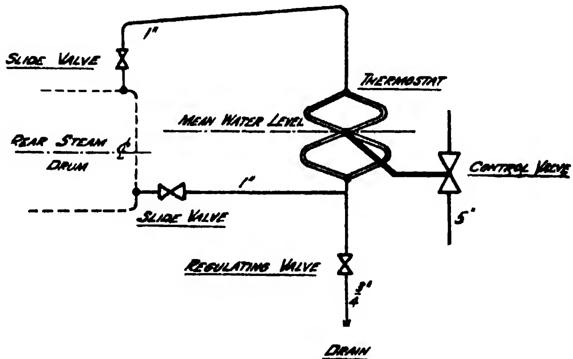


FIG. 237. Feed Regulator Connections.

be held rigid by means of clips fixed to steel angles or channels in the building framework. Spring supports have been tried, but do not appear to have been satisfactory. When a valve is blowing-off vibration is set up, and the periodicity of the springs synchronises

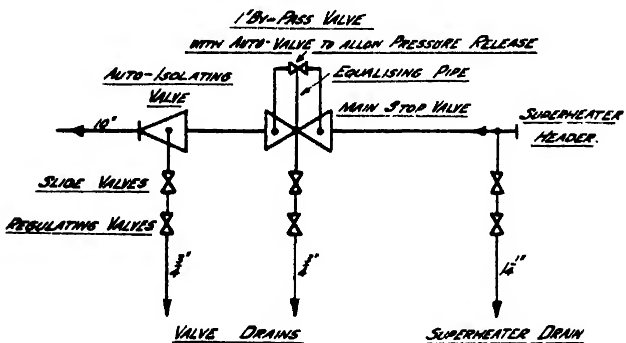


FIG. 238. Main Valve and Superheater Drains.

with that of the steam blowing-off. This results in excessive vibration which may damage the valves and supports.

Cast-iron rollers may be used for guides throughout the lengths of the piping. A suitable cravat sleeve should be provided where the pipe passes through the boiler-house roof.

The pipes from each safety valve of one boiler may be taken out separately or alternatively led to a common pipe which is then

carried through the roof. This piping is made of solid hot-drawn mild steel designed to suit the steam conditions. The economiser safety valves are connected by branch pipes to the boiler blow-down or drain tank, and the material is similar to that for the steam valves.

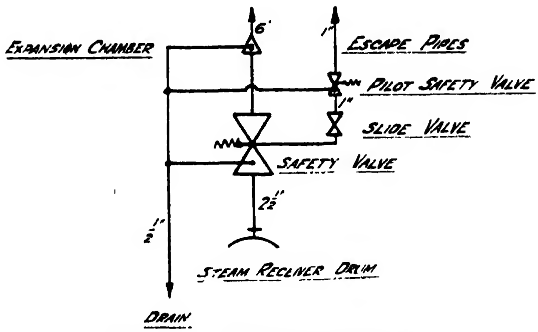


FIG. 239. Safety Valve Drains.

The safety valve is placed at the economiser outlet to ensure water flow through the economiser during blowing off and prevent overheating of the tubes by the flue gases.

Atmospheric Exhaust Pipework. This includes the main exhaust from the condenser together with all auxiliary exhausts such as the steam oil pumps, steam feed pumps, ejectors and drain tank. These auxiliary exhausts are all connected to the main exhaust

FIG. 240. Air Valve Connections.

pipe. Provision should be made for drainage, and it is usual to include a syphon complete with valve and piping led to a convenient position. The piping may be either of cast iron or mild steel plate, the latter being lighter. The bore will be fixed by the turbine manufacturer. The main exhaust pipe is run straight out of the condenser and taken up the outside wall preferably at the boiler-house side.

Town, Service Water and Other Pipework. There are numerous other sections of piping of varying sizes and materials.

Service water system	Induced draught and secondary air-fan bearing cooling, boiler feed pump bearing cooling,

	ash pump gland sealing and cleaning, boiler and condenser filling, coal bunker service, general cleaning, etc.
Town water service .	Emergency make-up water, CO_2 instruments, drinking fountains, etc.

Fire service (river or other supply), fire pumps, etc.

Circulating Water Pipework. The system commences at the suctions of the circulating water pumps and terminates at the outfall in river or sea layouts and at the cooling towers, where these are in use. Figs. 241 to 245 show some usual schemes.

The layout will depend on site conditions and the station capacity. Care should be taken to include means for sectionalising to permit of efficient and convenient operation of the plant and allow for extensions. With small and medium size river stations it is usual for each set to have a separate circulating water system. When cooling towers are used a bus-main with section valves is usual. For large capacity river stations a sectionalised ring main appears to be favoured.

The pipes may be mounted on overhead structures or laid direct in the ground. The overhead system is simple and probably cheaper to install, a disadvantage being cleaning and painting. In some cases a combination of both methods have been used and have proved satisfactory. Where large pipes are used (36 in. to 74 in. diameter) and site conditions permit, the pipes will nearly always be laid in the ground. The pipes are of cast iron or mild steel plate but the latter material should be limited to sections of pipework mounted overhead or above ground and those buried in concrete. In some cases large pipes and bus-mains have a reinforced concrete lining (gun process) of from 1½ to 2 in. Bitumen-lined mild steel pipes are also used.

The nature of the ground in which pipes are to be laid should be ascertained in case of contamination by injurious chemicals and danger of subsidence. To guard against the latter the pipes may be laid on concrete rafts. Where pipes have to be buried in ground made up of ashes it is found that a good covering of clay affords protection. In one installation a minimum thickness of 18 in. was used for preserving the pipes from corrosion by water percolating through ashes containing a considerable amount of sulphur. In one case cast iron having 0·5 per cent. nickel content for protection against salt-water corrosion was used. At certain sections of the pipe routes it may be necessary to provide reinforced concrete bridges to carry rail tracks or roadways.

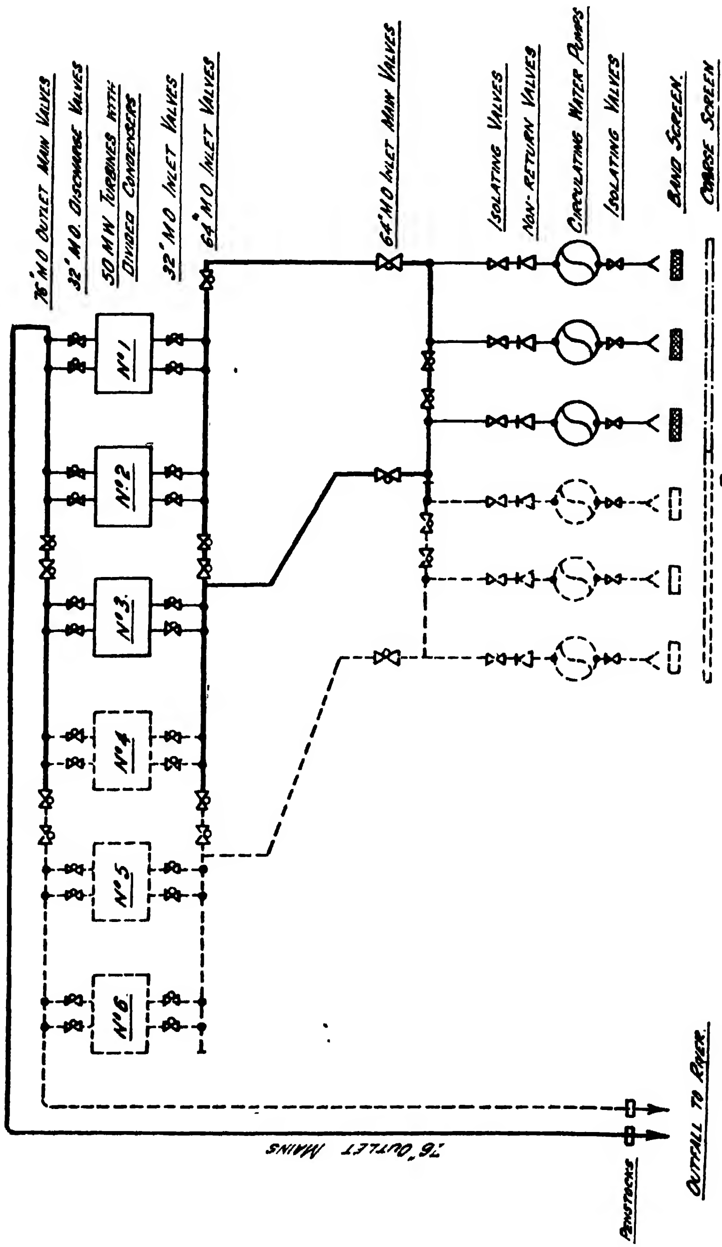


FIG. 241. Circulating Water System for 300 MW Riverside Station.

A careful survey should be made of the site and the positions of the various items of plant for the completed station should be known.

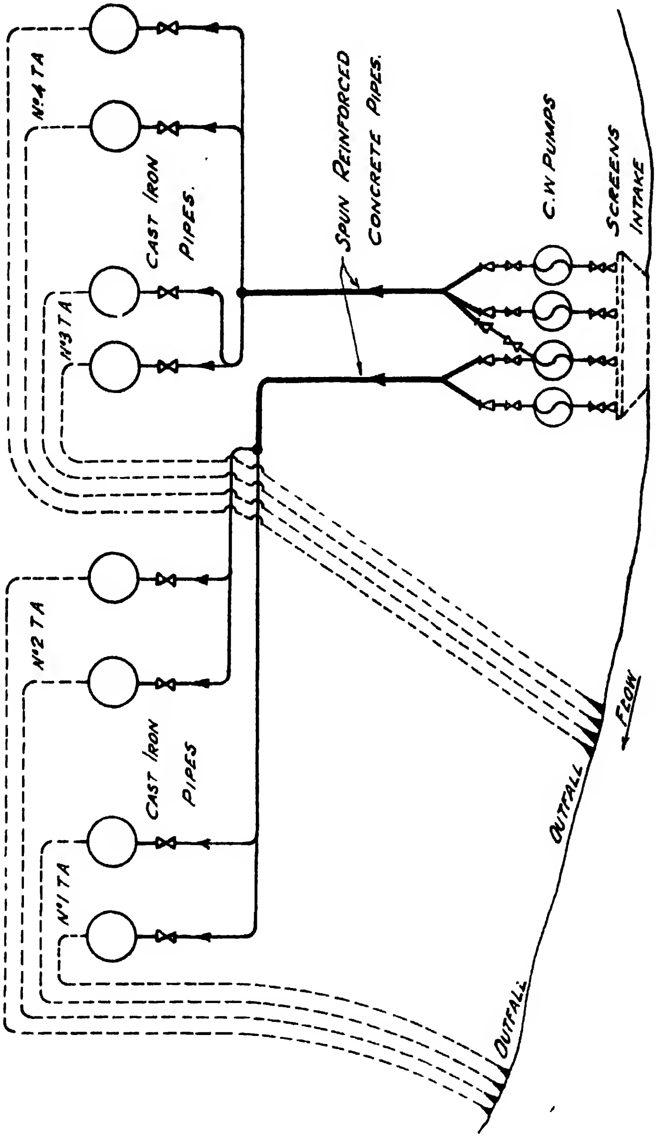


FIG. 242. River Circulating Water System.

The sizes of pipes will depend upon the condensing plant and auxiliary cooling water required.

The velocity of the water varies between 3 ft. and 14 ft. per second throughout the various sections of pipes. The following are general :—

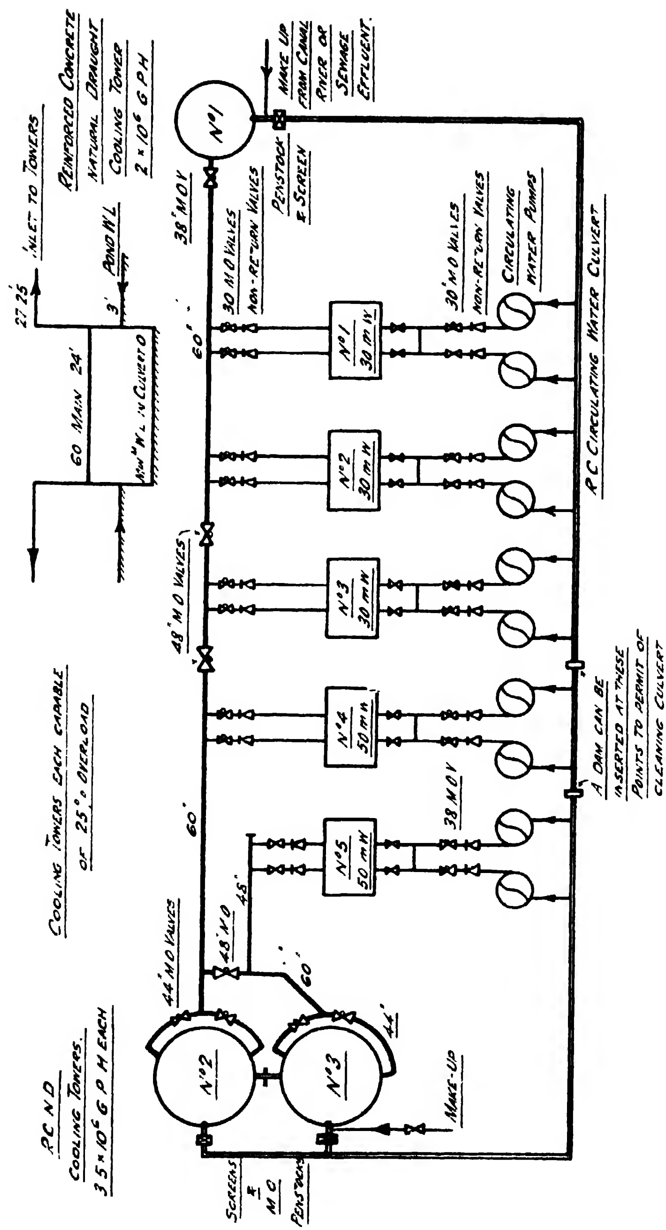


FIG. 243. Circulating Water System for 190 MW Cooling Tower Station.

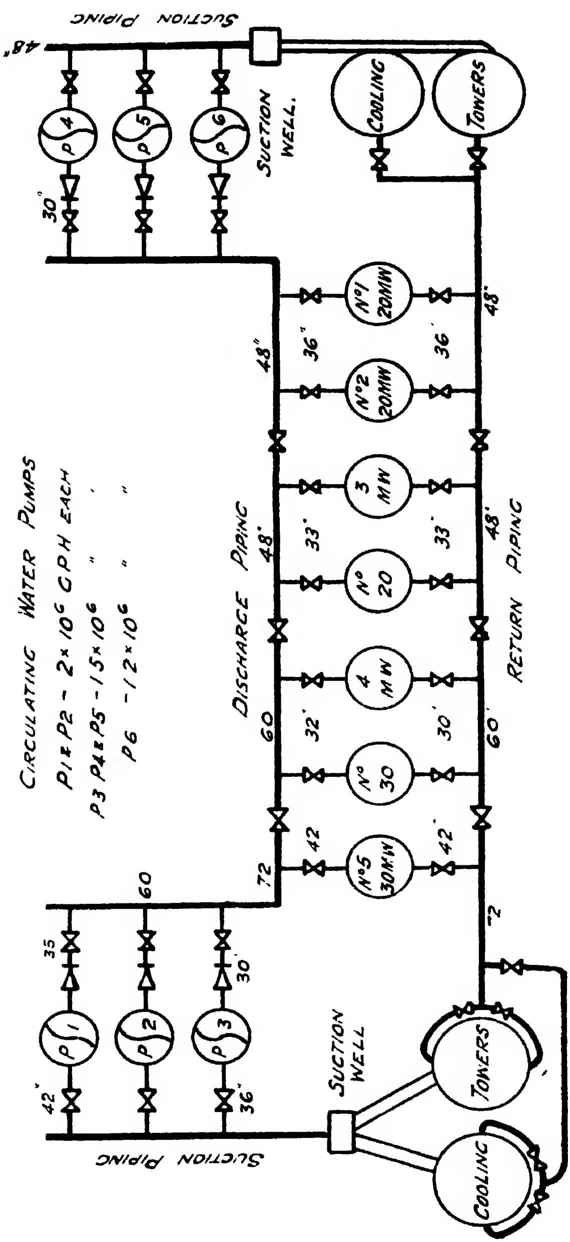


Fig. 244. Cooling Tower Circulating Water System.

Pipe bore—inches.	Velocity—feet per second.
6	8
12	9
24	10
36	11
48	12
60	14

The pipe thicknesses and details are generally in line with the appropriate British Standard Specifications.

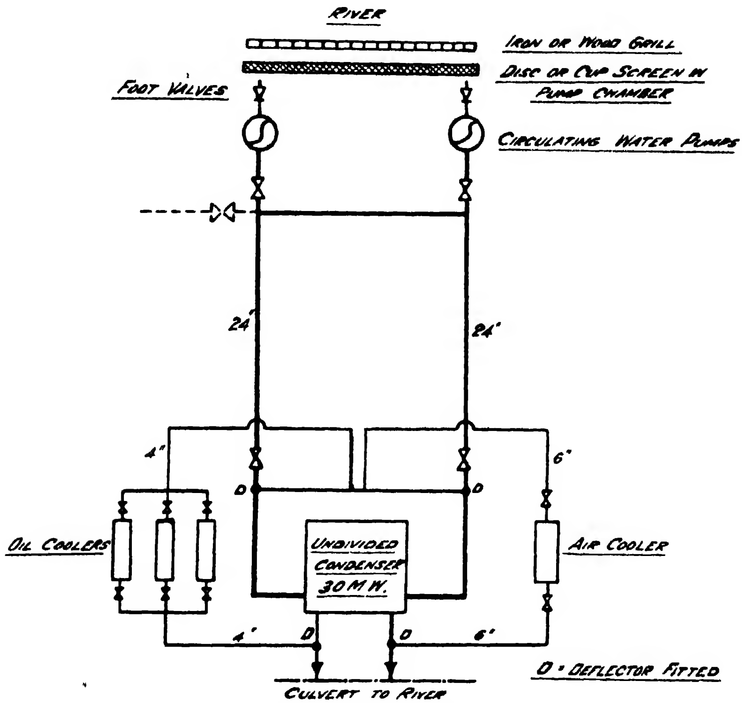


FIG. 245. Circulating Water System for 30 MW Set.

With cast-iron pipes, spigot and socket joints are usual, except where connections are made to valves, pumps and expansion joints, in which cases flanges are provided. Where wide variations of temperature obtain (outlet pipes discharging warm water), an open joint between spigot and socket is usual, but otherwise the solid joint, spigot and socket is general. The former allows for expansion, thereby obviating special expansion pipes. Spigot and socket joints are made with spun yarn and molten lead or lead wool. To facilitate caulking the spun yarn may be immersed in boiling

tallow, this having the effect of consolidating it whilst caulking, and removing the springiness. Rubber insertion or corrugated brass rings are used for flange joints. The flange joint is stronger and much easier to connect and disconnect than the spigot and socket joint, but the latter is flexible and lends itself to laying direct in the ground without trouble due to settlement. Expansion pipes or make-up pieces are of steel or copper corrugated types. Expansion pieces are fitted to the inlet and outlet connections at the condenser and thick rubber expansion pieces have been used and found suitable.

Valves should be provided to enable any section of piping being drained, and air cocks should be included. Manholes are desirable to give access for inspection and cleaning and should be included at convenient positions. Branches for cooling water supplies to oil and air coolers and other services are also required.

The pipes should be anchored at all bends, the anchors being capable of withstanding thrusts from hydraulic pressure and expansion.

Circulating water pipes and valves are pressure tested at the manufacturer's works to a pressure of from 50 to 100 lb. per square inch. The completed pipe system is pressure tested on site after completion to a pressure of 30 lb. per square inch. The system may be completed before testing, but this necessitates the trenches being left open for a long period. Lengths of piping may be tested and then filled in. Lengths varying from 150 to 200 ft. can be tested. Flanges are provided at these positions to permit the fitting of blanking or bulkhead plates.

Before dispatch to site, all pipes should be given one coat of bitumastic paint.

Valves. It will be seen that the valves required vary over a wide range of pressure and temperature for steam and water services.

The design and construction of any valve should be such that it fulfils the purpose for which it is included, namely, to control the flow of steam, water, oil or air as the case may be.

Valves of similar make, size and type should be interchangeable. A bye-pass valve is required whenever the main valve might be called on to be open slightly for warming up purposes, etc., as such a use will cause damage to the seating of an expensive valve, whereas a much cheaper bye-pass valve may be used, and this can be designed so that its seating is not damaged by "wiredrawing." This bye-pass valve may also in certain cases be able to equalise

the steam or water pressure on each side of the main valve, and so render the latter easier to operate.

Valves are of the internal or external screw types, the threaded part of the spindle of the former is inside the valve and in the latter it is outside. The internal screws are subjected to attack by steam or corrosive water passing through the valve and should never be used unless the conditions are favourable. The external screw valve is more expensive, but is preferred for all high pressure and high temperature steam and water services and in some cases the circulating water system.

The parallel slide type is nearly always used for high pressure high temperature pipework. Special materials have been introduced and valve failure is a rare occurrence in well maintained plants. Low carbon molybdenum steel or ordinary cast steel have both been used for valve bodies.

The accumulation of pressure between the discs of high pressure parallel slide steam valves is eliminated by fitting an automatic pressure release. Slackening, displacement and fracture of valve seats have been experienced with higher temperatures. Seats have been pressed or shrunk into place, but apparently the pressure and shrink fits are not able to deal with the differing creep rates between seat and body metals. Welding is sometimes resorted to, but as an alternative the seat may be formed by deposition of a suitable alloy on the metal of the valve body, thereby providing a homogenous combination and eliminating the usual seating ring.

Difficulties have been experienced with non-return valves in circulating water systems due to reversal of water flow (pumps shutting down), resulting in severe mechanical and hydraulic shocks on the pumps and piping. The design of large non-return valves should be such as to ensure shock-free closing which necessitates the flaps (doors) reaching the closed position as soon as the forward flow ceases. The slam in a valve is produced by the reversed water stream taking control of the flaps and forcing them on to their seats at the corresponding water velocity.

Such happenings are possible on long pipe lines where delay in closing may cause serious water hammer ; also on low head systems where the length of pipe is so short in relation to the static head as to cause almost instantaneous flow reversal when pumping ceases. Slanting seats and spring closing devices have been provided on such valves and both Glenfield and Kennedy and Blakeboroughs Ltd. have manufactured suitable valves. The increased weight of flaps, head loss and free working bearings all deserve attention.

Electrical and mechanical operation of all large high pressure valves is favoured and the latest schemes incorporate automatic operation of associated by-pass valves in sequence. A special feature has been made of this equipment by providing a control pedestal having signal lights to show the position of any main valve and its corresponding by-pass valve.

The boiler stop valves are sometimes arranged to close by electrical operation in addition to the more usual manual facilities.

Whilst it is desirable in the interests of capital cost and maintenance to reduce the number of valves to an absolute minimum the pipework system for any service should be sectionalised to facilitate maintenance and provide for isolation in case of emergency. In particular it should be possible to disconnect any length of steam main not in service and so prevent condensation. Where there is a possibility of water lying in a pipe charged with superheated steam, excessive stresses will be set up due to unequal expansion on the joints, resulting in failure. Care is also necessary when charging feed ranges, particularly where the pressure and temperature of the water is high. Vaporisation is almost sure to take place when charging an empty line.

The mounting and positions of valves should provide easy access for operation and if possible valves should be arranged for vertical operation. Where valves for steam and hot water have to be inverted, drip trays are necessary. Access to all valves must be made easy, so that inspection and overhaul can be made as required. This access should take the form of a permanent structure, such as a platform, gangway ladders, etc., and should be arranged as to be safe for the men to work at them.

The most important assembly of valves is that associated with the steam receivers, there may be from six to ten valves varying from 10 to 14 in. bore.

If the receivers are placed in the turbine house basement or on an intermediate floor near the boiler house side, valves may be arranged for manual or electrical control from the turbine operating floor, either in linear or circular formation. In some plants, the receivers are placed in the boiler house basement (Fig. 224), a satisfactory layout being obtained by building into the dividing wall a valve control panel. The valves are arranged for manual control from the turbine house basement whilst the turbine valves are fitted with electrical control for operation from the turbine operating floor. The drain valves on the main turbine valves are also provided with remote mechanical control from the operating floor. The panels

may be cast iron, so constructed that any panel may be removed to give access to a valve and its controls. Pressure gauges, if fitted, may be mounted on these panels. A platform with hand railing should be included to give access to the controls and operating hand wheels. The unit system of one boiler per turbine obviates the use of receivers.

A typical steam valve test for a normal working pressure of 650 p.s.i. and 850° F. is given.

A hydraulic pressure test of 975 p.s.i. was first applied to each side in turn with the valve closed, after which a water pressure test of 1,300 p.s.i. was applied with the valve open.

The valve was then subjected to a steam test of 650 p.s.i., 850° F. temperature, each side of the valve being tested. The duration of the tests was 30 minutes in each case.

Steam Traps and Drainage. The function of a steam trap is to remove automatically the condensation from a steam pipe or pressure vessel. The general principle of the majority of traps is that a valve is arranged to open automatically when water collects and to close again as soon as the water has been discharged. With high working pressures, troubles are experienced due to scoring of the valve seat, choking by grit, etc., as the water is discharged from the traps at full pressure. Steam traps should have a by-pass arrangement to permit of the trap being isolated for inspection or removal. A testing connection discharging to atmosphere will show when the pipe line or vessel is completely drained. Each atmospheric connection should be taken to an open tundish. The connections from the tundishes may be taken to a header which is led to the drain tank or alternatively to waste (Fig. 246).

A steam trap opening and shutting suddenly is liable to cause water hammer in the heaters and pipework.

A continuous flow trap of the ball float operated type is preferable to the thermal and bucket types.

A large quantity of water is produced during the warming-up period and hand drains should be included to carry this off. A master valve connected as close as possible to the pressure part, and another valve at the most convenient operating position is satisfactory. This second valve is then used as a regulating valve and can take any cutting action due to the valve being " cracked " open. The first is a slide valve and the other a mushroom type.

Messrs. Hopkinson Ltd. have a " Series Uniflow " valve which avoids the use of two valves in series. The unit comprises a master valve and a regulating valve in a single housing and is so designed

that the master valve must be fully opened before the regulating valve can be opened, and the regulating valve must be completely closed before the master valve can be closed. This arrangement protects the master valve from any possibility of wire drawing and ensures perfect fluid tightness. Steam traps which do not function correctly are often responsible for pipe joint failures. Some engineers have gone so far as to dispense with steam traps, having resorted to hand drainage. This is made possible by providing two valves as mentioned above, and including a length of piping between the valves. This is similar to draining off water and sludge from a turbo-alternator oil tank. The master valve is first opened and the water allowed to drain into the pipe; this valve is then closed and the

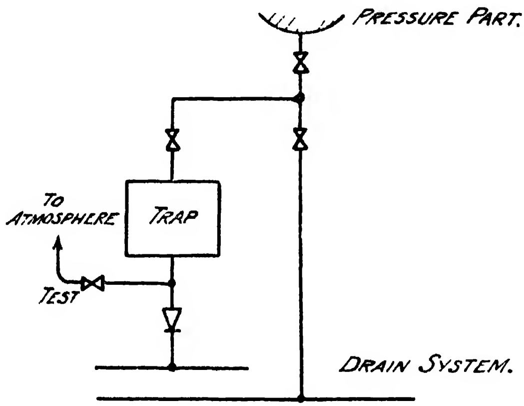


FIG. 246. Steam Trap Connections.

second or regulating valve is opened whereupon the water is discharged.

Hand draining necessitates continuous supervision by the operating staff.

Pipe Joints and Jointing Materials. The flanges of all steam and feed pipes should be forged or machined from the solid and may be attached to the pipe by screwing, welding or riveting. Screwed-on flanges should be bored and tightly screwed with a vanishing thread to ensure that the full thickness of the pipe is obtained at the back of the flange where the greatest stress occurs. The flanges are screwed to the pipes and then expanded. Screwing is satisfactory for pipes not exceeding 7 in. bore. Welded-on flanges are used on large diameter pipes for high pressure working. Riveted flanges are also used for large diameter pipes. An objection to this type of flange is that they have a tendency to leak at the rivet holes. Good riveted

TABLE 38. *Chemical Analyses of Bolt Materials*

Purpose	Carbon per cent.	Silicon per cent.	Man-ganese per cent.	Phos-phorus per cent.	Sul-phur per cent.	Chromium per cent.	Molyb-denum per cent.	Nickel per cent.
Bolts for feed pipes 850 lb.–300° F.	0·3–0·35	—	0·5–0·6	0·04	0·04	—	—	—
Bolts for steam pipes 625 lb.–850° F.	0·38–0·45	0·1–0·3	0·5–0·7	0·05	0·05	1·25–1·5	0·7–1·0	0·5

throughout and thereby eliminates concentration of stress ; further, it is cheaper. Steam and feed pipe stud bolts are screwed British Standard fine thread with bright steel nuts. The steel bolts are screwed British Standard fine thread to obtain the greater strength of the increased bolt area. In some cases the feed piping bolts are screwed Whitworth thread. Special bolts and nuts should be stamped with an identification mark to distinguish them from ordinary steel. The nuts for the special alloy steel studs used on the steam pipes are sometimes made of a similar material to that of the studs. Bright mild steel nuts have been used on 750° and 850° F. ranges, although cases are on record where distortion and creep have resulted in joint failure and seizure of the nuts. Painting the threads of the bolts with a mixture of graphite and oil and ensuring that the threads do not protrude through the nuts reduces the risk of seizure between bolts and nut. Nuts have also been dipped in copper to prevent seizing. Steam piping subjected to full temperature should have bolts made from 60 to 70-ton alloy steel (625 p.s.i., 850° F.). Bolts for feed piping should be made from 30 to 40-ton steel (850 p.s.i., 300° F.). For all other services the bolts and nuts may be of 28 to 32-ton mild steel.

Jointing materials are required for plain-bolted joints, but not for seal-welded joints. Seal-welded joints have highly polished machine faces. For plain-bolted joints of pipes over 2 in. bore, a highly polished machine finish dead flat and true is specified when steel serrated rings are used. The details of the rings vary according to the size of pipe.

		1 in. bore	8 in. bore
Thickness of ring over serration		$\frac{1}{4}$ in.	$\frac{3}{8}$ in.
,, ,, under serration		$\frac{3}{16}$ in.	$\frac{5}{16}$ in.
Overall diameter	. . .	$3\frac{1}{8}$ in.	$12\frac{5}{8}$ in.
Number of serrations per inch	.	16	12

The possibility of the accumulation of water at joints should be avoided, otherwise joint failures are always possible. Cases are on record where steel serrated rings have disintegrated, apparently due to attack from corrosive water lying in a well over the joint. Such failures have been attributed to corrosive fatigue.

Fig. 248 shows the temperature variations on one feed line joint.

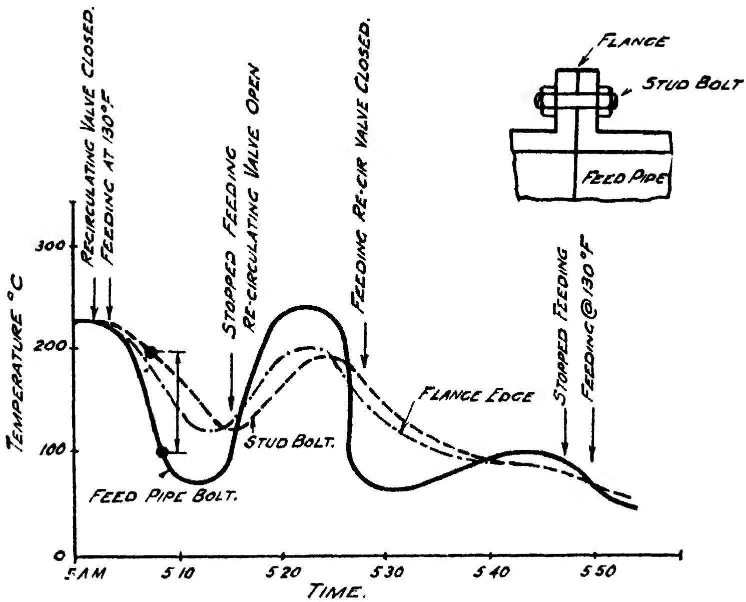


FIG. 248. Temperature Variations on Feed Pipe Joints.

For plain-bolted joints of pipes 2 in. bore and under, the flange faces may have a coarse gramophone finish for nickel corrugated joint rings and jointing material. The foregoing joint particulars have been found quite suitable for working steam pressures of 700 p.s.i. and 850° F. temperature. For a steam pressure of 300 p.s.i. and temperature of 750° F. and a feed water 500 p.s.i. and 300° F. corrugated nickel rings and graphite paste are suitable for all piping. In one station this method of jointing was used on all pipes up to 14 in. bore and found satisfactory. In another installation the following were used with success :—

High-pressure steam (300 lb., 750° F.)	Serrated ring with 0·008 in. Klingerite.
Feed water (500 lb., 300° F.) .	Serrated ring with 0·008 in. Klingerite.
Low-pressure steam . . .	Corrugated ring and compound.

In one 375 p.s.i. 720° F. station the pipe flanges connected to valve flanges are made with serrated jointing, the pipe and valve flanges being machined plain on the face. The flanges are bolted together without any jointing ring or material, *i.e.*, a metal-to-metal joint. Jointing materials which may perish or disintegrate under high temperature and pressure are eliminated.

The flanges of all other piping such as town main water, low-pressure water and atmospheric piping may be machined and jointed with corrugated brass rings and compound. The corrugated rings should be thinly smeared on both sides with graphite or jointing compound.

A manganese paste makes a sound job, only a thin worm of paste being applied to the centre of the face otherwise difficulty will be experienced in breaking the joint. The remainder of the face can be smeared with the graphite or jointing compound.

Failure of pipe joints may be due to cupping of flanges caused by unsuitable jointing rings, whilst troubles after re-making may be reduced by using fitted bolts.

Pipe Supports, Wall Boxes, etc. The system should be anchored at definite points to limit the maximum expansion and contraction strains, and it is usual to make the receivers these anchor points, although in some cases the anchoring is such that movement is free in one dimension whilst fixed in the other two dimensions.

Supports between anchor points require some consideration, as it may be found that these are either ineffective when the pipe is hot, or else cause undue strains by restricting the free movement of the pipe. The supports, anchors, slings, straps and rollers should be suitable for all working conditions of the pipework. The pipes should be free to move on their supports in any direction except at the point of anchorage, the supports being designed to take up any difference in level whether the pipes are hot or cold. The strains set up by expansion are safeguarded by bends or straight lengths of corrugated piping. The summation effect on a long length is reduced by anchoring the pipe at intervals, the expansion on each section being taken up by the corrugations and creased or crimped bends. The movements set up by expansion or contraction are thus minimised and controlled. The supports should be arranged so that any one pipe may be withdrawn without disturbing the remaining pipes.

Roller supports require a considerable area of bare pipe for bearing surface, whereas slings may be arranged without impairing the pipe coverings. Spring supports will be necessary for vertical

pipes. Wall boxes and floor collars should be provided where the pipes pass through walls and floors. These should be so designed that they may be placed in position after the pipes are fixed.

Lagging. As steam temperatures increase, so the quality of the lagging used has to change to enable that part next to the pipe to withstand charring and other chemical or physical change which will destroy its strength or insulating properties. The annual value of heat loss is much greater than is generally suspected, since : (1) It goes on at maximum rate all the time the pipeline is under steam pressure, irrespective of the load on the turbine ; (2) the value of the heat loss to the turbine is very high, being about 15° F. for each 1 per cent. increase in coal consumption. To reduce the heat losses all steam and feed ranges, including receivers, separators, valves and flanges should be lagged with a non-conducting covering. The ideal form of insulation would be for the pipe surface to be completely surrounded by stagnant "still air," but since this is impracticable, non-conducting materials are resorted to. In general, the smaller and the more numerous the air spaces the better will be the insulating value. Materials which are themselves good conductors of heat can give low values of thermal conductivity when arranged in the form of a low density mass, *e.g.* steel wool. Many of the insulating materials used are either prepared from naturally porous substances or have artificially produced air cells. Heat is transferred through an insulation by a combination of all three physical processes, radiation, convection and conduction, but for convenience the term "thermal conductivity" is used as a measure of the materials' capacity to transmit heat. Thermal efficiency of an insulation depends on temperature and on pipe size. It is defined as :

$$T_e = \frac{\text{bare surface loss}-\text{insulated loss}}{\text{bare surface loss}} \,.\, 100.$$

Care is required in the interpretation of the result so obtained, for a high efficiency is possible with corresponding increased heat loss.

Insulation surface temperature is not always a reliable indication of heat loss, since a finish of brightly polished aluminium sheet will raise the surface temperature but also reduce the heat loss. The basis for determining insulation thickness recommended by the British Standards Institution is the economic thickness method.

An insulating material should possess the following characteristics :—

(1) It should have a high insulating efficiency.

(2) The mechanical strength should be such that it will not be adversely affected by vibration, knocks or rough handling.

(3) The material should be unaffected by moisture, leaky joints, etc.

(4) Its chemical composition should under no circumstances cause corrosion of the pipe.

(5) The material should be easily applied or removed.

(6) It should not be too costly.

To show how saving is effected by including non-conducting material the following figures are given. The heat loss from an uncovered pipe is said to vary from 2·5 to 4·5 B.Th.U. per square foot of external surface per ° F. in temperature difference per hour. Taking a 10-in. outside diameter pipe and a length of 100 ft. with a steam temperature of 850° F.,

$$\begin{aligned}\text{External surface} &= \pi dl \\ &= \pi \times \frac{10}{12} \times 100 \\ &= 262 \text{ sq. ft.}\end{aligned}$$

$$\begin{aligned}\text{Temperature difference} &= 850 - 70 \quad \text{Assuming building tempera-} \\ &= 780^\circ \text{ F.} \qquad \text{ture is } 70^\circ \text{ F.}\end{aligned}$$

Taking 3·5 as the average heat loss, then 3·5 × 780 × 262 B.Th.U. per hour per 100 ft. of pipe with coal having a calorific value of 11,000 B.Th.U. per lb. and a boiler efficiency of 85 per cent.,

then $\dfrac{3{\cdot}5 \times 780 \times 262 \times 0{\cdot}85}{11{,}000} = 55$ lb. as the equivalent loss in coal per hour.

Assuming coal costs 15*s*. per ton, then the yearly loss will be

$$8{,}760 \times \frac{55}{2{,}240} \times \frac{15}{20} = £160.$$

By applying a non-conducting covering it is reasonable to assume that a saving of 80 per cent. will be effected, or approximately £130 per annum.

Some specifications state that the maximum rate of heat loss should not exceed 0·25 B.Th.U. per hour per square foot of surface per degree difference in temperature. In deciding upon the temperature at which heat insulation and lagging should be applied, a knowledge of the temperature of every exposed portion of the plant is desirable. One specification provided for the inclusion of lagging and heat insulation to every exposed portion of plant which operated

at a temperature above 120° F., including the surge and storage tanks.

In certain sections of the piping system, *e.g.*, drain pipework, it will be necessary to provide a suitable covering where contact is likely to be made by the operatives. All flanges should be covered solid with the pipe. A separate width of material, Fig. 249, being carried over the flanges to enable this portion of the lagging to be removed and give ready access to the bolts. A similar construction is desirable for valves and fittings. Fig. 250 gives an alternative method. Lagging applied to steam pipes, etc., can have special expansion joints incorporated to prevent cracking due to temperature and vibration.

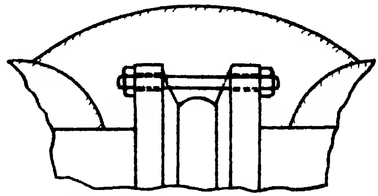


FIG. 249. Joint Lagging.

To cover flange joints, valves, etc., with planished steel covers packed with loose asbestos is not altogether satisfactory. The lagging materials used for pipework and fittings are magnesia, asbestos, cork, slag wool, aluminium foil and glass silk together with special heat-resisting compounds. Each material has its charac-

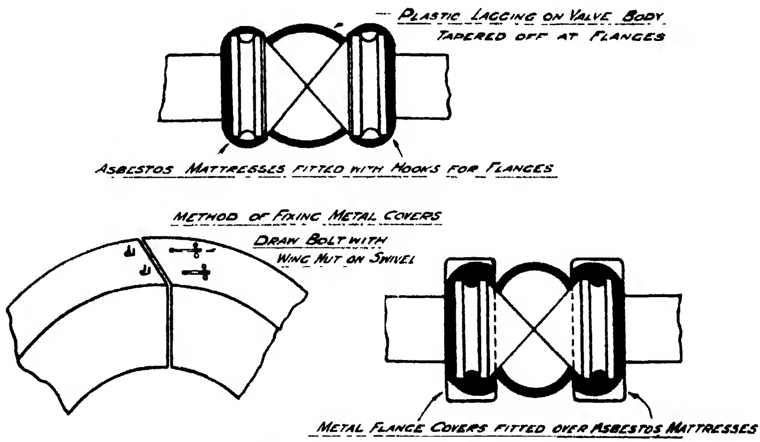


FIG. 250. Pipe Joint Heat Covering.

teristics in relation to temperature and working convenience. The most commonly used is a mixture of 85 per cent. magnesia and 15 per cent. asbestos fibre, which is applied in a plastic state. The effect of putting magnesia covering on to a high temperature pipe

or vessel is to decompose the inner layer of magnesia. This, in its primary stages, consists of dehydration and subsequently of disintegration of the material itself, into magnesium carbonate and carbon dioxide. Magnesia, when subjected to very high temperature, breaks down into asbestos fibre and powdered magnesium oxide, and therefore destroys cohesion between the insulation and the pipe. For very high temperature duty it is necessary to apply a requisite thickness of high temperature-resisting material under the magnesia.

Cases are on record where pipes have corroded due to water leaking into the magnesia covering, necessitating pipe replacement. Plastic magnesia has to be applied to the pipes whilst they are warm, whereas glass silk can be applied with them cold. Unless care is taken when placing in position, air spaces may be left so reducing the efficiency. Pipes for service over 850° F. have been bound with asbestos rope at 18 in. centres and then given a layer of glass silk reinforced with wire netting. At first it would seem that such an air space would be a good insulator since the air is held static in small gaps between the strands of rope. The major part of the heat is transmitted by radiation at this high temperature and the pure air space at this temperature has no effect on the radiation and the air space only increases the outside diameter of the insulation and consequently the heat loss. Glass silk has the advantage of cleanliness, is non-inflammable and withstands vibration and rough handling without losing its form or thermal efficiency. The packing density is varied according to requirements and varies between 7 and 10 lb. per cubic foot, but lighter packings are possible.

When in blanket form it can be cut to any shape, and being flexible can be wrapped round curved surfaces.

Strip or bandage is suitable for the insulation of pipes and bends, being wrapped spirally. The bandages are in various widths and thicknesses and are unbacked or backed with fabric, canvas or asbestos cloth, being sewn with asbestos yarn. Glass silk is supplied enclosed in wire netting, metal foil, expanded metal or asbestos cloth, thus providing rigid or semi-rigid types of insulation. Flexible sections are very convenient, being cut to the exact circumference of the pipe and then bent around it and temporarily secured with cord or wire. Wire netting is then fixed and pulled tight, after which a finishing coat is applied. Some typical details are given :—

Boiler Drums. Covering with "Versil" 1½ in. thick secured in ⅝ in. mesh galvanised wire netting supercoated with ¾ in. thickness of reinforced armouring cement trowelled to a smooth finish and painted two coats.

Efficiency : Assuming a maximum temperature of 500° F., the efficiency will be about 94 per cent. with a heat loss of approximately 0·245 B.Th.U. per square foot per hour per ° F. temperature difference.

Air Ducts. Insulated with "Versil" aluminium foil covered slabs 1 in. thick.

Efficiency : Assuming a temperature of 260° F., the efficiency will be about 89·7 per cent. with a heat loss of approximately 0·26 B.Th.U. per square foot per hour per ° F. temperature difference.

Gas Ducts and Fans. Insulated with "Versil" ¾ in. thick supercoated with ¾ in. thick cement enclosed with heavy jute canvas, sized, filled and painted.

Efficiency : Assuming maximum temperature of 450° F. the efficiency will be about 89 per cent. with a heat loss of 0·4 B.Th.U. per square foot per hour per ° F. temperature difference.

Pipework (750° F.). Covering with 1¾ in. "Versil" secured in ⅝ in. mesh galvanised wire netting supercoated with ¾ in. hard setting composition trowelled to a smooth finish and painted two coats of approved colour.

The following particulars relate to 850° F. and 300° F. steam and feed ranges respectively, using other lagging materials.

Steam Receiver and Steam Pipework. Lagged to a thickness of 3½ in. with plastic material of not less than 85 per cent. of plastic magnesia and 15 per cent. of asbestos fibre reinforced with galvanised wire netting and covered with ½ in. thick hard setting non-conducting composition, making a total thickness of 4 in. Lagging to be trowelled to a smooth face and covered by a wrapping of canvas or sail cloth properly secured and given two coats of paint in selected colours.

An alternative is ½ in. heat-resisting compound, 3 in. plastic magnesia and ½ in. hard-setting cement.

Feed Pipes. Covered with 1½ in. of plastic material consisting of not less than 85 per cent. plastic magnesia and 15 per cent. of asbestos fibre reinforced with galvanised wire netting and covered with ½ in. thick hard-setting non-conducting composition, making a total thickness of 2 in. Finished in a similar manner to steam piping.

Small steam pipes and drains, etc., should have the same thickness of insulation as large ones, for the heat loss per square foot on a small pipe is higher than on a large pipe.

These notes apply to all boiler and turbine piping working at the temperature conditions stated.

Water pipes outside the buildings should be protected from frost and a ½ in. thick covering of hair felt with an outside covering of canvas is suitable.

Cleaning and Painting. All pipes should be thoroughly cleaned both inside and outside before erection and putting into commission. Unlagged pipes, supports, etc., should be painted with one coat of priming paint before erection and finished off with two coats of anti-corrosive paint. Some form of colour scheme for the station pipework is useful and the following are given as a guide :—

Service	Colour
High pressure steam piping	Signal red
Low ,, ,, ,,	Pink
Feed water piping (main)	Navy blue
,, ,, ,, (reserve)	Ditto with red band on each length of pipe.
Condensate piping	Blue
Town water ,,	Aluminium
Drain water ,,	Black
Drain (clean water and steam) piping	Brown.
Compressed air piping	White C
Boilers (integral)	Admiralty grey
Oil piping	Yellow
Circulating water	Black or as required
Atmospheric exhausts and pipes leading thereto	To suit machine

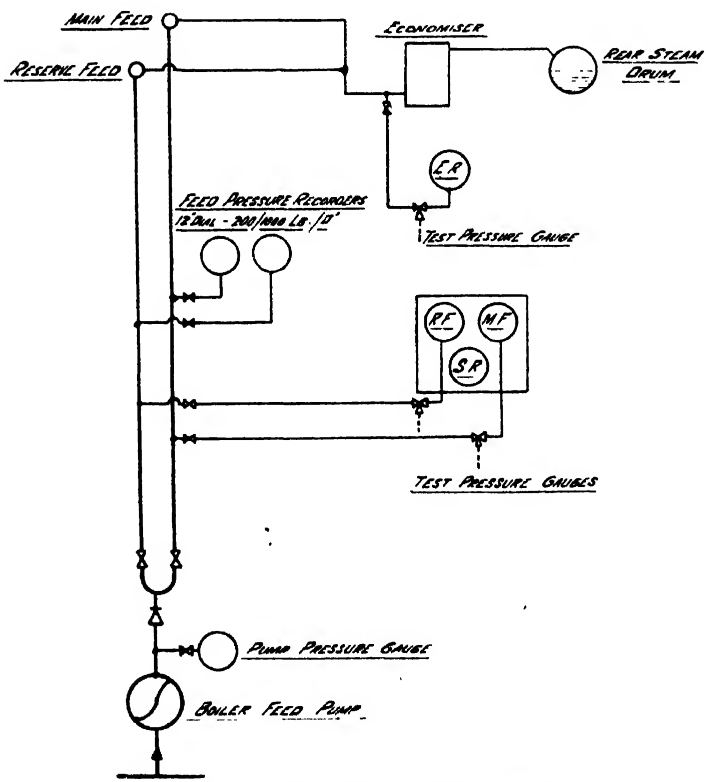


FIG. 251. Feed Water Pressure Gauges.

A list of recommended colours together with identification marks are given in the British Standard Specification, and this is helpful when drawing up a colour scheme. It is usual to paint the

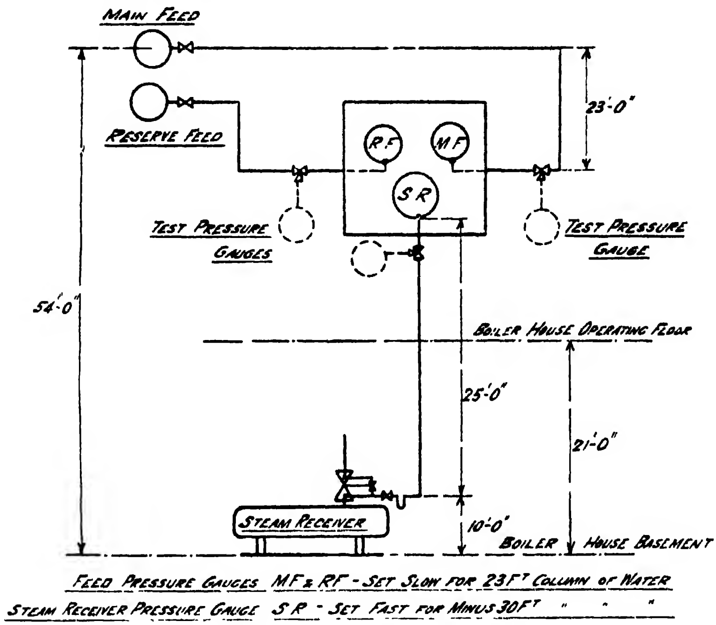


FIG. 252. Steam and Feed Range Pressure Gauges.

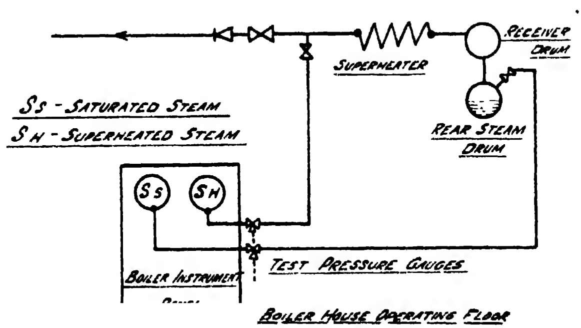


FIG. 253. Boiler Steam Pressure Gáuges.

pipes above the turbine house floor level the same colour as the machines, and include a thin line of the corresponding colour to each pipe. The full colour would commence immediately below operating floor level.

As an alternative the various pipework may be designated by different colour bands.

Instruments, etc. The usual instruments in main steam and feed ranges are steam and water flow recorders, pressure gauges and occasionally pressure recorders in the feed ranges.

The steam flow meters are generally associated with the individual boilers and turbines, but in most cases the pipework contractor

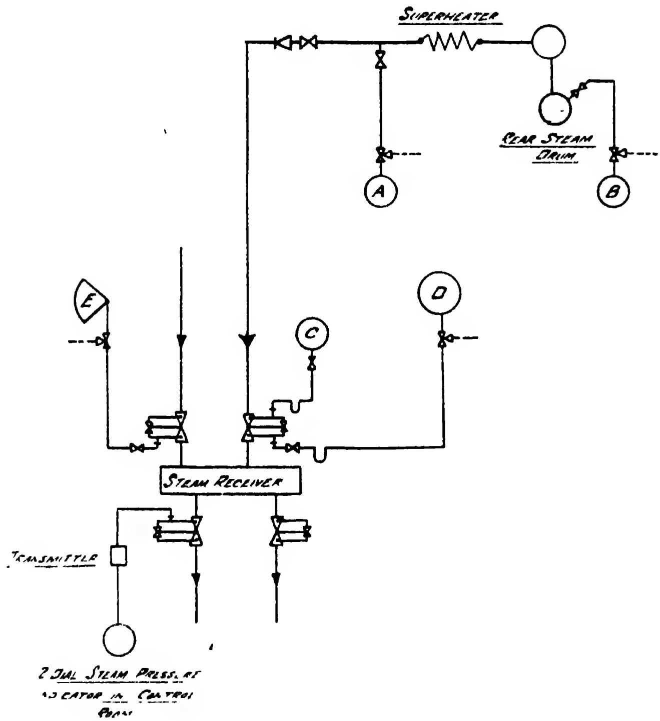


Fig. 254. Steam Pressure Gauges.

will be required to fit the necessary orifice plates in the steam lines. The piping in which these plates are inserted have to comply with certain requirements regarding length of straight pipe and position, and the actual pipe bore must be given. Similar remarks apply to the venturi tubes or orifice plates, whichever be fitted for water-flow records.

A critical pressure gauge is included in the boiler-house instruments, and this is connected to the steam receiver. The ordinary pressure gauge is not sufficiently sensitive to indicate any deviations

until conditions have changed considerably. A critical pressure gauge is extremely sensitive, and there is no time lag in indicating pressure conditions between steam demand and combustion control,

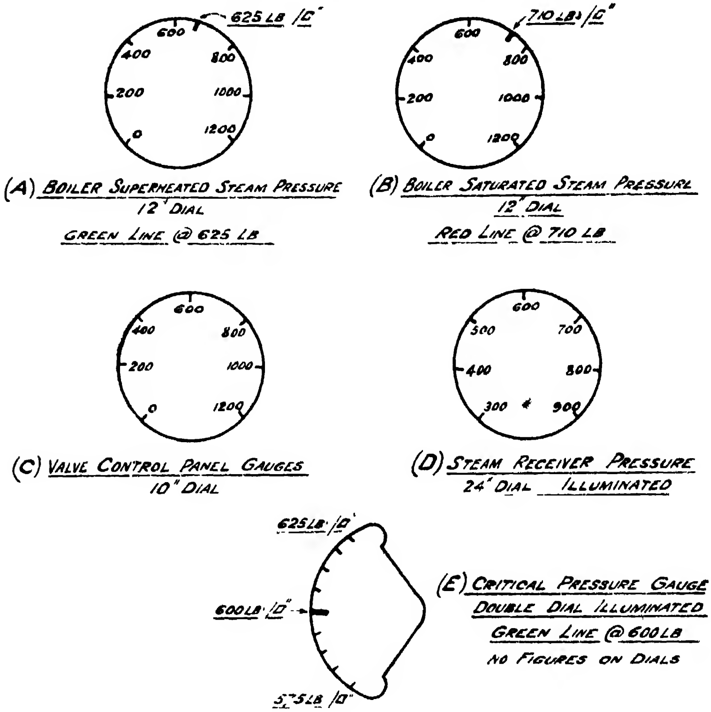


FIG. 255. Steam Pressure Gauges. *See also* Fig. 254.

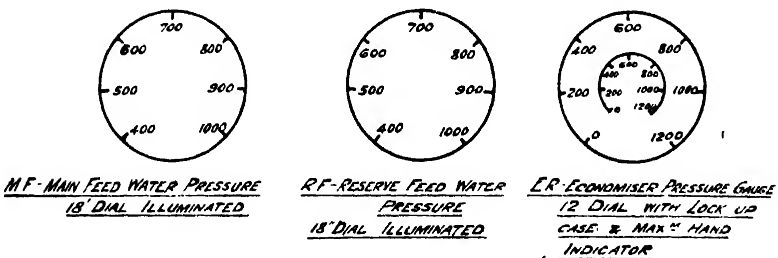


FIG. 256. Feed Water Pressure Gauges. *See also* Fig. 251.

thus affording the boiler operator ample time to make the necessary adjustments. The gauge may be of the single- or double-dial patterns. The scale on each side of the centre mark is graduated to indicate from 5 lb. above or below normal working pressure, according to the

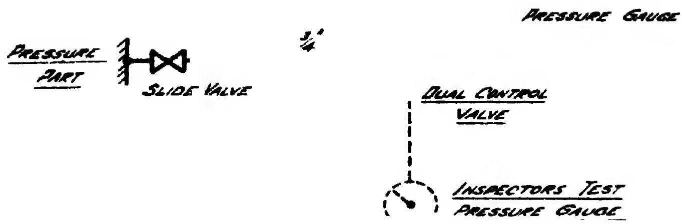


FIG. 257. Pressure Gauge Connections.

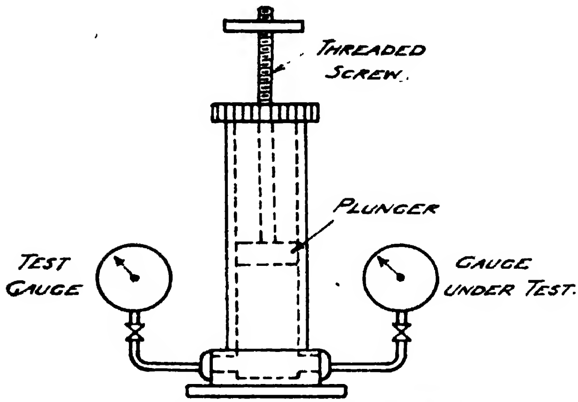


FIG. 258. Pressure Gauge Tester.

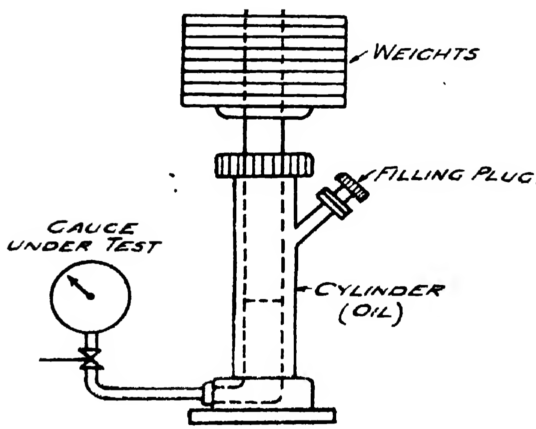


FIG. 259. Deadweight Pressure Gauge Tester.

degree of sensitiveness required. If it is too sensitive the pointer may be liable to "hunting" and a reasonable margin above and below should be allowed. For a working pressure of 600 lb. a figure of 25 lb. on each side is suitable, and for a working pressure of 300 lb. a figure of 10 lb. on each side is satisfactory. Electrical contacts for operating an alarm (bell or lamp) may be included in the equipment.

Main and reserve feed water pressure gauges and pressure recorders are also included. Pressure gauges should be marked in accordance

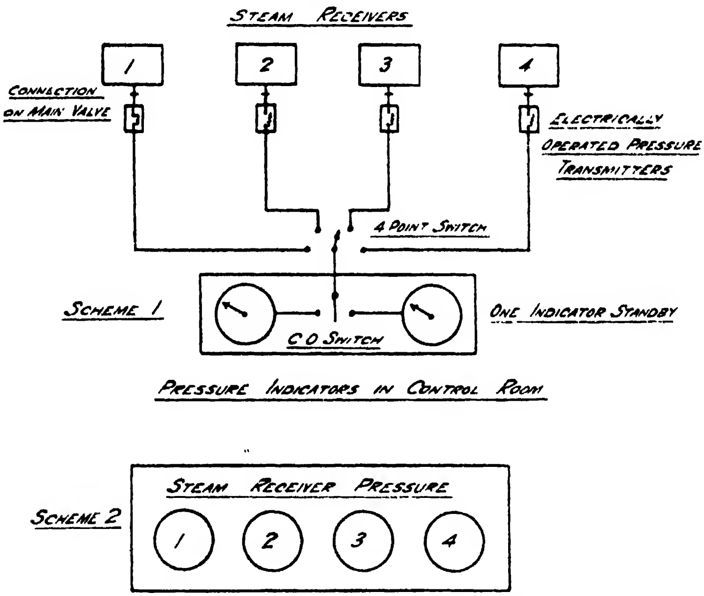


FIG. 260. Steam Pressure Indicators in Control Room.

with the requirements of the Factories' Acts. The various instruments and connections to the different services are shown in Figs. 251 to 257. To facilitate the testing and calibration of pressure gauges, it is desirable to have a gauge tester. Two types are shown in Figs. 258 and 259. Fig. 260 shows remote indicators.

Plant Operating at Different Pressures and Temperatures. In some plants which commenced with a working pressure of 350 p.s.i., it has been found economically justifiable to raise the pressure to 650 p.s.i., and even 1,200 p.s.i. The low-pressure boilers may be obsolete and the older turbines will need to be supplied from the high-pressure boilers, or alternatively the high-pressure boilers will

augment the low-pressure plant during peak periods by transferring surplus steam. It is necessary to install a reducing valve and desuperheater to reduce the steam pressure and temperature to the requirements of the low-pressure turbines (Fig. 261). A further step towards efficient plant operation is the inclusion of a combined surplus and reducing valve. In this way the efficient high-pressure boilers may be operated at their most economical rating by passing over surplus steam to the low-pressure range. The number of safety valves included on the low-pressure side should be such that they can safely pass the maximum quantity of steam for which the reducing valve is designed. The mounting of the safety valves should be such that vibration is reduced. All valve and pipe joints between the reducing valve and desuperheater are subjected to a very high temperature and special alloy steel bolts should be fitted to avoid creep and so prevent joint failures.

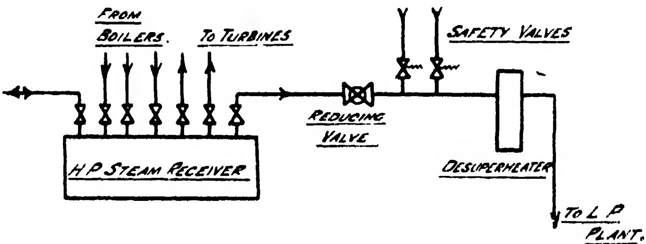


FIG. 261. Combined H.P. and L.P. Steam Plants.

Care is required in the selection of reducing valves for cases are on record where such valves had to be placed in a separate annex on account of the excessive noise. A typical reducing valve and desuperheater specification for a 650/200 p.s.i. range is as follows : Reducing valve to be capable of reducing 225,000 lb. of steam per hour from 650 p.s.i. 850° F. to 200 p.s.i., this steam to be desuperheated to 750° F. producing 230,000 lb. of steam per hour at 200 p.s.i. 750° F.

Low-pressure Steam System. The provision of steam for gland packings, air ejectors, oil pumps, soot blowers, etc., becomes a problem in very large stations. To avoid the use of high-pressure high-temperature steam it is possible to provide a low-pressure pipe system which takes a supply from the primary or main steam system through servo-controlled reducing valves to afford a 200 p.s.i. supply.

CHAPTER IX

TURBINES

Number of Sets. The commitments of the undertaking having been ascertained and the outputs of the machines fixed it now remains to choose the number to be installed. Assuming machines of the same type, interchangeability and facilities for layout and extensions, the number may be determined as follows :—

Basis 1. One machine running and dealing with full load.
One machine standby.
One machine under maintenance.

Basis 2. Two machines running and dealing with full load
One machine standby.
One machine under maintenance.

Basis 3. One or two machines running and dealing with full load.
One machine standby.

Interconnection with an external source of supply reduces the number required, since the standby machine could be undergoing maintenance and need not be ready to take load in emergency. Basis 1 shows the maximum installation with maximum security of supply, but the capital cost would only be justifiable where rapid growth of load was anticipated, demanding the early installation of a fourth machine. The condition then becomes as in Basis 2 with 50 per cent. of the installed plant in operation as against 33 per cent., the security of supply being maintained. Unless spare plant be installed every additional machine to meet increase in load lowers the security of supply and it is here that overload capacity becomes an important factor in the consideration of capital cost.

It is therefore desirable to arrive at a suitable ratio between the normal running overload and spare plant capacities, which would include that under maintenance. Another point to bear in mind is that large machines are more economical than the equivalent capacity in small machines. It is probable that a medium output machine, or perhaps two, would be installed to deal with periods of light load or even peak loading. In some stations one or two small machines varying in output from 2·5 MW to 10 MW have been included to serve station requirements, particularly in case of failure of the main units. Where site conditions permit there has been a tendency to plan a station for six machines, ranging from 30 MW to 80 MW each, but in view of the dislocation of important

services in case of failure or destruction of such huge plants, it appears that the maximum capacity of a station would be limited to 500 MW.

As an example, economy and ample security of supply would be met in a six-unit installation of which four are supplying the normal economical load and are capable of, say, 25 per cent. overload ; one standby ready to go on load at short notice, and the other under maintenance. In this case 66 per cent. of the installed plant is dealing directly with the load and is also capable of meeting ordinary peak demands. Present-day practice appears to allow for the largest set being out of commission when considering independent operation. Typical station data are given in Table 39. Since the

TABLE 39. *Station Data*

Station	Probable Ultimate Capacity MW	Initial Installation		Speed R.P.M.	Voltage kV.	Remarks.
		No of Sets	M.C.R. Output MW			
Battersea . .	500	2	69	1,500	11·0	—
		1	105	,,	,,	Includes 1–5 MW House set.
Barking "B" .	300	2	75	1,500	12·5	1–3·5 MW House set.
		1	3·5	3,000	3·0	
Clarence Dock .	400	2	50	1,500	7·3	
Fulham . .	300	2	60	1,500	11·0	1–10 MW House set.
		1	10	3,000	6·6	
Dunston "B" .	300	3	50	1,500	13·5	1–2·5 MW House set.
		1	2·5	3,000	3·0	
Ironbridge . .	200	1	50	1,500	9·5	
Swansea (T.J.) .	240	2	30	3,000	33·0	1- 0·75 MW Diesel Eng. House set.
Sheffield (B.M.) .	185	1	25	3,000	11 0	
		1	30	,,	,,	
Sheffield (N.) .	130	2	30	3,000	11·0	
Leeds (K) . .	180	2	25	3,000	11·0	
Birmingham (H.H.)	200	3	30	1,500	11·0	
Oldham (S.V.) .	150	3	12·5	3,000	6·6	
Kearsley . .	125	2	32	1,500	11·0	
Littlebrook . .	240	1	60	1,500	15·0	
		2	30	3,000	13·2	
Derby . . .	90	1	10	3,000	6·6	Plant installed.
		1	20	,,	6·6	
		1	30	,,	33·0	
Ferrybridge . .	150	2	20	,,	10·5	,,
		2	45	,,	,,	
Bradford . .	130	1	30	,,	33·0	Also 1–2·5 MW set
		1	30	,,	6·6	
		1	20	,,	,,	
		2	22·5	,,	33 & 6·6	

nationalisation of the supply industry in this country many new power stations have been built or are in the course of construction, and full details will be found in the annual reports of the British Electricity Authority. General data are given in Chapter I.

Layout. The layout of the turbo-alternators (alternators are dealt with in Volume 2) to a large extent decides the positions of all turbine house auxiliary plant and equipment. Various layouts have

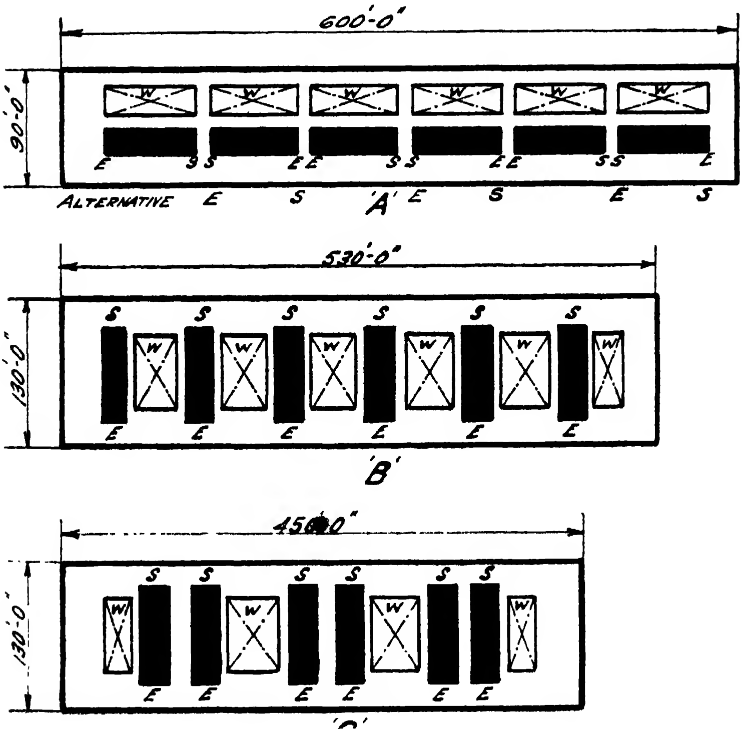


FIG. 262. Layouts of Turbo-Alternators for 300 MW Station.

been adopted from time to time to suit site conditions, but in general they fall into one of those shown in Fig. 262. Departures from standard layouts are almost unavoidable however in modernised stations, chiefly due to restricted basement height and desirability of having the boiler feed pumps near the feed heating plant, which is kept as close as possible to the turbine. In many of the older stations the condensate was taken to large underground hot wells in the boiler house, the boiler feed pumps being grouped to form a central pump house near these wells.

A turbo-alternator requires little or no attention during operation apart from logging of the routine instrument readings and in view of this it would be possible to place it at a higher level surrounded by a gallery. This would eliminate the operating floor common in stations and the basement would become normal operating level, Auxiliary plant requiring attention would be at one level which would facilitate operation and reduce labour charges, and further it would allow of all plant to be handled by the station overhead

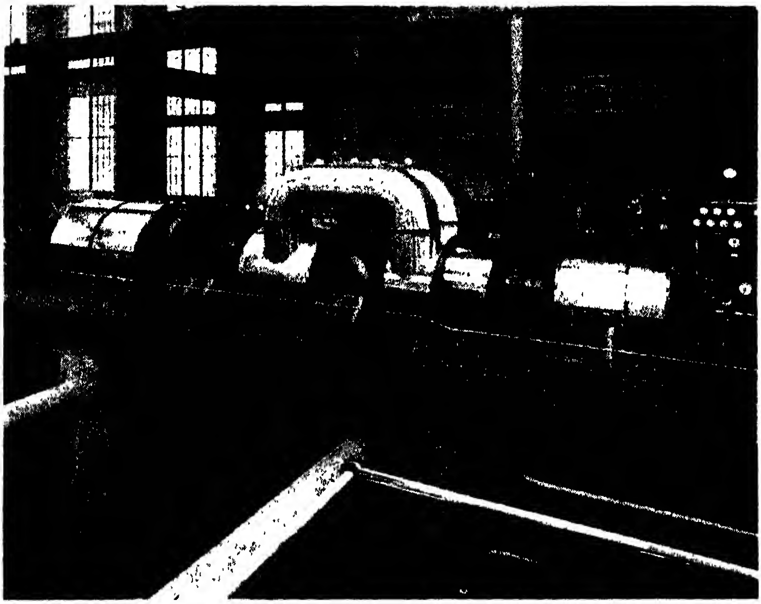


FIG. 263. 25,000 kW. 3,000 r.p.m. Three-Cylinder Turbo-Alternator, Blackburn Meadows Power Station, Sheffield. (English Electric Co. Ltd.).

cranes. The height of the basement will depend on the type of turbines installed and will be considerably reduced if the cross-over connections are taken overhead. The layout of the turbo-alternators should meet the following requirements :—

(1) Occupy a minimum of space thereby ensuring economy in buildings.

(2) Permit of a simple layout of auxiliary plant and pipework and arranged to facilitate maintenance and inspection.

(3) Have a minimum crane span. This is important, due to increasing adoption of larger sized units.

(4) Be of good appearance when completed. Figs. 263 and 264 show two installations.

Commenting on the layouts given, it may be said that " A " and " C " have a common advantage over " B " in that the buildings are likely to be less, while " A " has the additional advantage of smaller crane span. On the other hand " B " and " C " offer better facilities both for steam and electrical connections, while " A " has the disadvantage in that alternate machines are of opposite hand. Probably the final choice would be either " A " or " C " depending upon local conditions. An alternative is to place the machines in two rows parallel to the centre line of the turbine house. With this

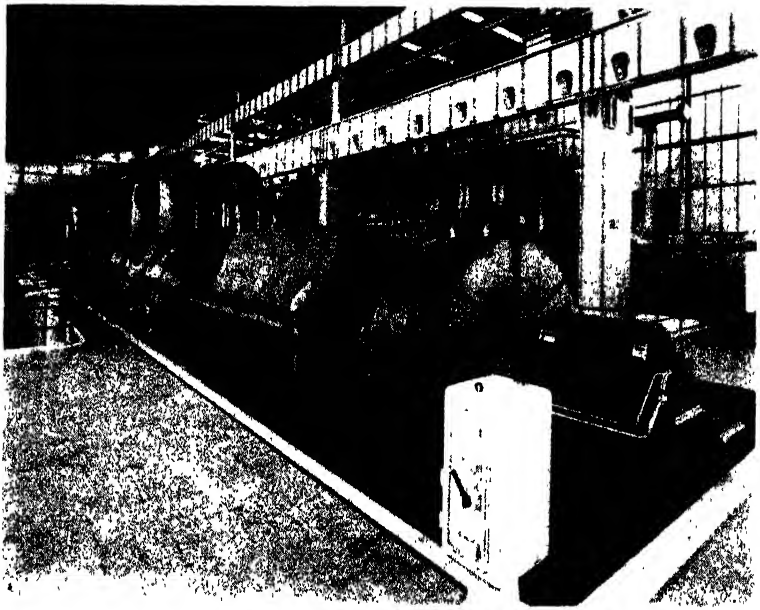


Fig. 264. 75,000 kW. 1,500 r.p.m. Three-Cylinder Turbo-Alternators, Barking Power Station (British Thomson-Houston Co. Ltd.).

layout they are staggered to facilitate arrangement of auxiliary plant and condenser tube and electrical rotor withdrawal, etc. To eliminate handling, the sets shown in layout " A " may be arranged with steam and electrical ends together. With the electrical ends together the same space provides for removal of both electrical rotors and a saving in overall length is obtained.

The inclusion of well openings (W) in the turbine operating floor give ready access to auxiliaries by stairways, and handling by an overhead crane. It also gives light to the basement and helps to maintain it at a normal working temperature. Wherever possible

there should be adequate space round the auxiliary plant to facilitate inspection and maintenance. There should also be sufficient space to permit the withdrawal of condenser tubes and this area should be kept free from cables and pipework. The chief auxiliaries in the basement are: Feed heaters, evaporators, extraction pumps, air ejectors, oil coolers, oil pumps, air coolers and ventilating fans (Fig. 265). In some stations the circulating water pumps and the

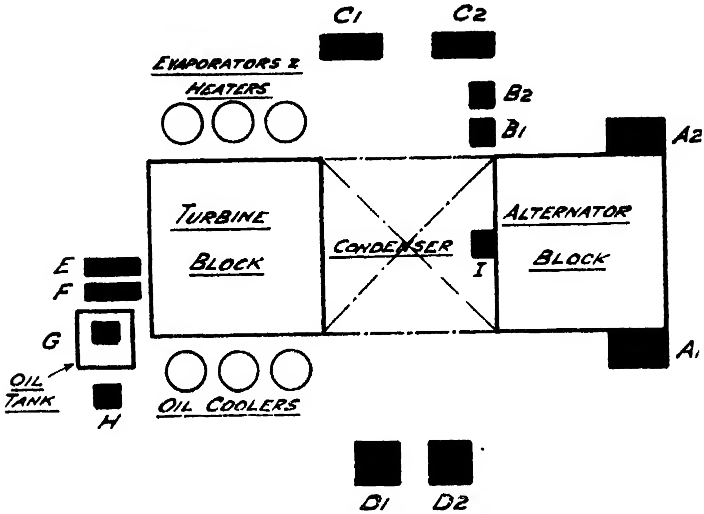


FIG. 265. Layout of Turbo-Alternator Auxiliary Plant.

A_1, A_2—Alternator vent fans.*
B_1, B_2—Extraction pumps.*
C_1, C_2—Boiler feed pumps (1 electric, 1 steam).
D_1, D_2—Circulating water pumps.*
E—Jacking oil pump.*
F—Flushing oil pump.*
G—Turbine auxiliary oil pump.
H—Oil purifier.
I—Barring gear.

* Located in turbine house basement, others operating at floor level.

lower voltage distribution switchboards serving the auxiliaries are placed in the turbine house basement. Where a separate feed pump bay is not included these pumps may be put in the basement. Advantage may be taken of the longitudinal layout to arrange all the circulating water piping to condensers, oil and air coolers on one side of the condensers, while all the condensate piping and bled steam connections are made on the opposite side. This leads to a comparatively simple arrangement of the condensate piping between the condensers and the boiler feed pumps.

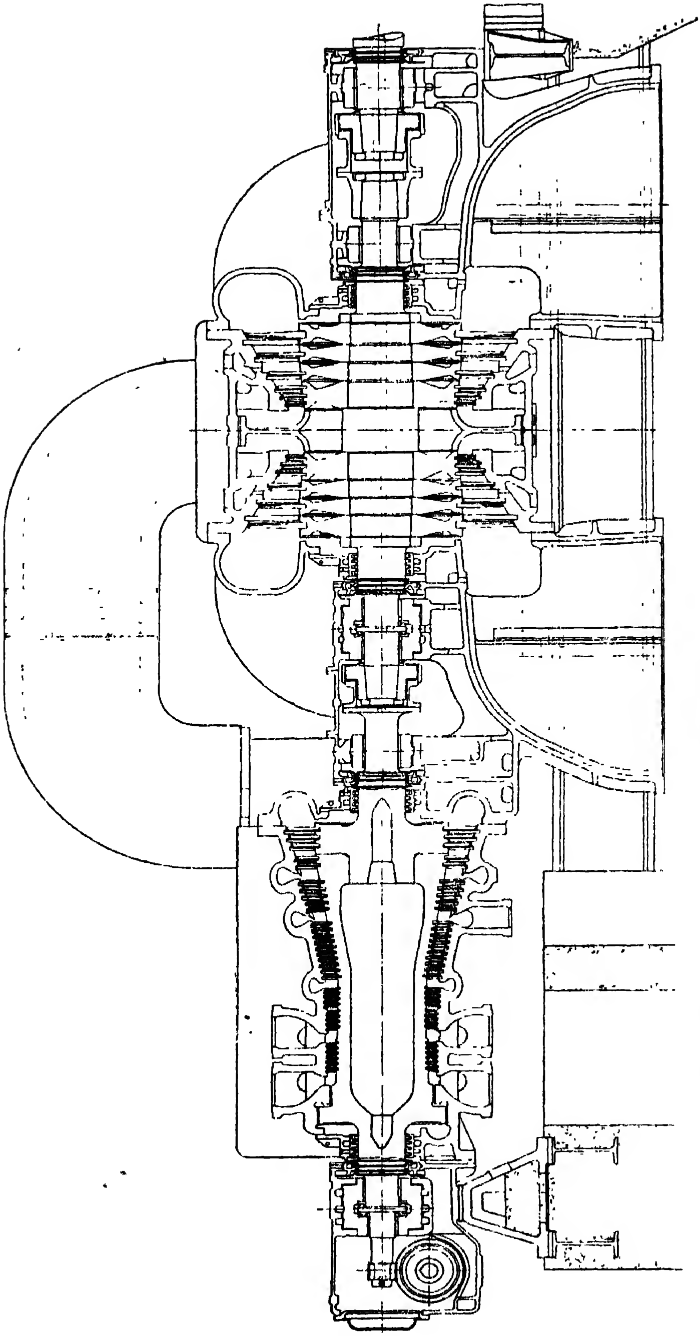


FIG. 268. Longitudinal Section, 30,000 kW., M.C.R., 3,000 r.p.m. (C. A. Parsons.)
Steam Conditions: 300 lb. per sq. inch, 750° F.

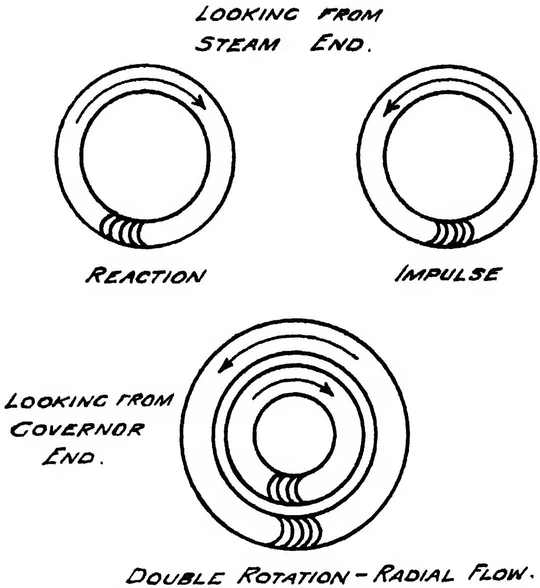


FIG. 269. Rotation of Turbines.

reaction is used it is to be understood that this refers to the "impulse-reaction" type of turbine. The practice in large output high speed sets is to include reaction blading at the low pressure end. The blade areas are large and therefore the leakage areas are proportionately small, and as a double-flow exhaust is used the end thrust is balanced. These arrangements enable the length of the turbine to be reduced.

Further Classification. As the output capacities and working conditions have affected the construction of each particular make it has been suggested that the following particulars be given for each turbine :—

(1) Number of shafts.
(2) Number of cylinders.
(3) Number of exhausts.
(4) Speed.

The trend in this country appears to be for all 30 MW sets to have two cylinders and 60 and 100 MW sets three cylinders. Designs with one cylinder fewer in each case are becoming available. Double casings for the high-pressure cylinder are being evolved with the space between in communication with the intermediate pressure stages ; the inner casings can thus be built in sections of alloys suitable to the temperature.

Back-pressure Turbines. Large back-pressure or pass-out turbines are rarely used, although the smaller units have their applications, some of which are :—

(1) Superimposed high pressure sets for improvement of thermal efficiency of existing plant.

(2) Auxiliary services—emergency drives, house service sets, feed water heating sets.

Such turbines are frequently employed in private power plants where process steam is required and the production of electricity is a by-product. The turbine is of simple construction and all the steam entering the machine is exhausted into the process main. A low-pressure condensing turbine is sometimes included.

Two back-pressure turbo-alternators taking steam at 600 p.s.i.g., 800–850° F. are installed at Battersea Power Station for supplying steam for local district heating. The sets are designed for an output of 1,350 kW. and 23×10^6 B.Th.U. per hour at 3 p.s.i.g. A description of this system is given in the *Air Treatment Engineer*, January, 1950, "District Heating in Pimlico."

Choice of Type. In large power stations using high pressures and temperatures the compound impulse and the axial flow reaction are most common although radial flow machines up to 65 MW, 1,500 r.p.m., have been adopted. The single shaft turbine is sound, simplifies operation and is general for small and medium sizes.

With radial flow turbines two alternators and two shafts are usual. Another case requiring two shafts is where it is economically justifiable by reason of high steam pressure to have a high pressure section running at a higher speed than a low pressure section. In deciding upon the number of cylinders the efficiency is nearly always of primary importance, and if this is to be a maximum with a large high-pressure turbine at least two cylinders will be necessary. A single-cylinder machine is cheaper in first cost than a multi-cylinder machine of the same output. It is possible to build single-cylinder turbines up to 80 MW at 1,500 r.p.m. and up to 30 MW at 3,000 r.p.m., but general practice favours multi-cylinder sets for these larger sizes and also to separate high-pressure and low-pressure cylinders if the initial steam conditions are high. In the latter case the multi-cylinder turbine has the advantage that the separate high-pressure cylinder and its components which are subjected to the initial high pressure and temperature may be kept reasonably small. In this way the stresses in these rotating and stationary parts may be kept within the safe limits of the materials available for use. Further advantages of the use of multi-cylinder sets are

that the diameters of the shafts may be kept within reasonable dimensions and designed to ensure that the critical speed is well above the running speed. The multi-cylinder turbine has resulted in a reduction of clearances rendered possible owing to the extremes of temperature in any one casing being reduced, thus enabling a turbine to be run up to speed much quicker than with a large single

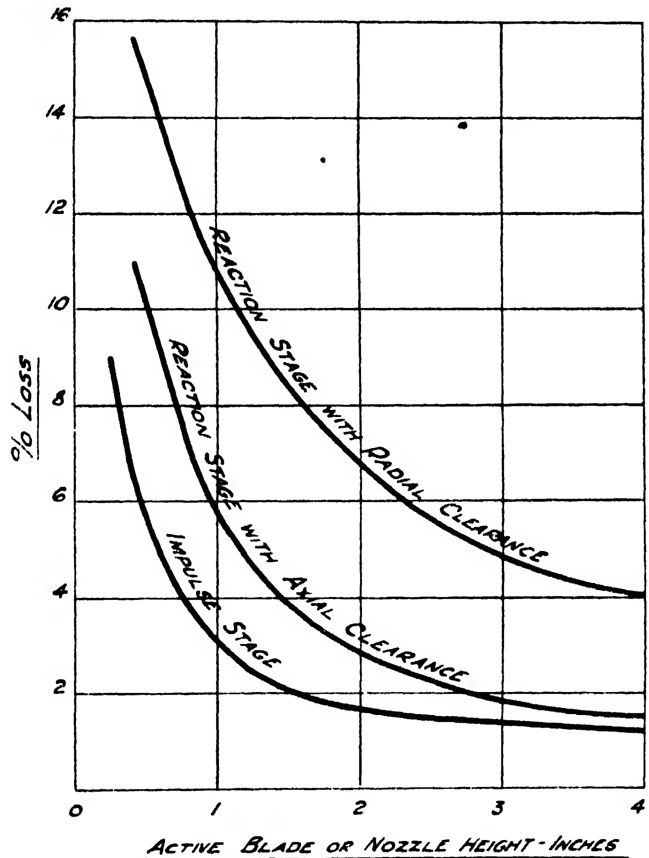


Fig. 270. Comparative Losses in High-Pressure Steam Turbine Blading.

cylinder. The reduction in diameter of the wheels and shortening of the shafts reduces the stresses and tendency to whip. In some designs of multi-cylinder turbines the H.P. cylinder is of the "pure-reaction" type or even combined impulse and reaction. Some manufacturers do not employ reaction blading in H.P. cylinders on account of the small clearances which are necessary to obtain

reasonably good efficiencies. The higher the initial steam pressure the smaller will be the blade heights at the H.P. end, and it therefore follows that the blade tip clearance with unshrouded blades must be very small to keep down the leakage over the blade tips. Alternatively, if the blades in high-pressure reaction turbines are shrouded to permit of safe blade tip clearances, the axial clearances must be kept very fine. Fig. 270 illustrates this point. The disadvantages are that the overall length of the turbine is increased thereby necessitating larger building space and introducing additional losses by the use of interconnecting piping. The number of exhausts to be used will depend chiefly on the size of the turbine. The output of a single exhaust turbine is governed by the area of the exhaust annulus, the latter being limited by the blade tip speed. Losses at the exhaust are composed of the leaving losses and exhaust losses. The former are due to the carry-over velocity of the steam leaving the last row of blades. This loss may be reduced by using a double or triple flow exhaust arrangement, which in turn increases the output of the set. On the other hand the gain is offset by the additional floor space and cost of accommodation. A small drop in pressure must exist if steam is to flow from the last wheel to the condenser, and the heat energy required to produce this flow and make up for the losses due to eddies, etc., is termed the exhaust loss. With a given maximum exhaust area and given back pressure the output is limited if the efficiency is to be maintained and not impaired by high leaving and exhaust losses. To overcome this difficulty at the exhaust end turbines are usually of the multi-cylinder type arranged with single or double flow in the low-pressure cylinder. With large output and low speed, a two-cylinder turbine with a single-flow low-pressure cylinder can be used, as the low speed enables the requisite exhaust area to be obtained in a single exhaust.

The simplest type is the single-cylinder turbine, for it is compact and has few parts. Single-cylinder turbines with duplex exhausts (Fig. 271) are also adopted. The duplex exhaust turbine consists of two sets of low-pressure blading on the rotor, through which the steam flows in parallel, the two streams being brought together in the exhaust branch. With the double-flow turbine the axial thrust is balanced, since the flows are in opposite directions. The steam enters the L.P. cylinder at the centre of its length and flows to an exhaust at each end. The thrust on the blading is thus balanced, and no dummy pistons are necessary. In turbines having an intermediate cylinder the steam flow may also be arranged in the opposite direction, thus balancing the thrust. If the steam enters the H.P.

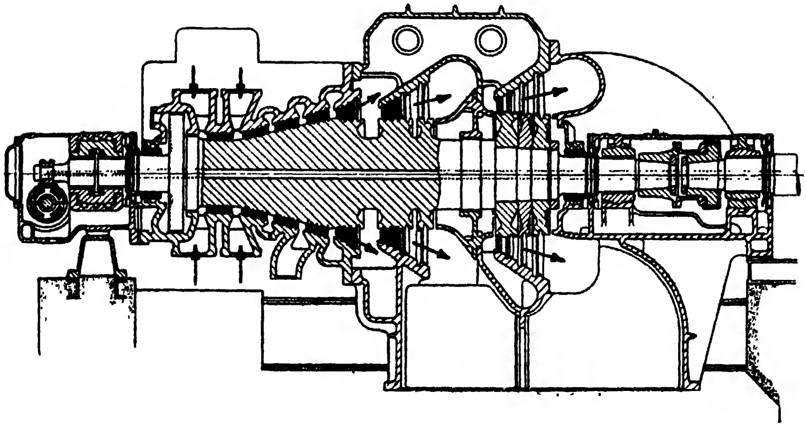


FIG. 271. Single-Cylinder Turbine with Duplex Exhaust. (C. A. Parsons.)

turbine at the end nearer the centre of the set, this point of admission results in a much cooler governor and oil pump end than in conventional designs. The volume of steam leaving the last wheel of a large turbine is enormous and it is more efficient and cheaper to discharge it to two or more condensers. Turbines to give 30 MW and 3,000 r.p.m. are quite common, but above this rating high vacua necessitate the use of special designs to obtain the requisite exhaust area in the last wheel to reduce the leaving losses. The use of two low-pressure cylinders has been resorted to in some installations.

TABLE 40. *Losses on Typical "Pure Reaction" Turbines*

Continuous maximum rating .	. MW	10	20	30	50	100
Windage and friction loss * .	per cent.	10	10	10	10	10
Blade efficiency	,,	90	90	90	90	90
,, clearance loss . . .	,,	6·5	5·0	4·5	4·0	3·5
Wetness loss	,,	2·3	2·5	2·6	2·7	2·8
Reheat gain	,,	5·2	5·0	4·9	4·8	4·7
Nett blade efficiency . .	,,	86·35	87·41	87·71	88·00	88·29
Governing or throttling loss .	,,	0·5	0·5	0·5	0·5	0·5
Dummy and gland loss .	,,	2·5	2·3	2·0	1·7	1·5
Leaving loss	,,	2·0	2·0	2·0	2·0	2·0
Internal efficiency . .	,,	82·03	83·21	83·76	84·3	84·75
Mechanical loss	,,	1·2	0·9	0·75	0·60	0·45
Alternator loss	,,	4·5	3·8	3·2	3·2	3·0
Efficiency at alternator terminals	,,	77·35	79·29	80·2	81·09	81·82

Losses are at 80 per cent. C.M.R.

* This item chiefly represents friction in the blade passages.

These figures are based on steam conditions of about 600 p.s.i. and 800° F. The losses shown must be used as factors, for example, in the case of the 10 MW unit the nett blade efficiency is the blade efficiency 90 per cent. multiplied by 0·912 multiplied by 1·052 equals 86·35 per cent. It will be appreciated that the figures are approximate and are for general information only and may not necessarily represent figures for any particular machine that may be offered because of the various commercial considerations that must always be taken into account. Up to 60 MW output a speed of 3,000 r.p.m. would most likely be selected and for 100 MW—1,500 r.p.m.

Table 41 gives approximate losses in Impulse type of machines which may serve as a general guide.

TABLE 41. *Losses in Impulse Turbines*

Continuous maximum rating	MW	0·5	30
Nozzle loss *	per cent.	9·0	5·0
Blade loss *	,,	9·0	7·0
Windage and friction	,,	3·0	0·5
Diaphragm Leakage	,,	5·0	0·75
Gland loss	,,	3·0	1·0
Mechanical loss	,,	2·0	0·75
Governing loss	,,	1·25	1·0
Total	,,	32·25	16·0

* Reheat, carry-over, etc., included in nozzle and blade losses.

The performances of the various types for a given output are very similar and the choice of make is usually decided by the capital cost, steam conditions, output, speed, efficiency, and the opinions of the engineers concerned.

Theoretical Considerations. The steam passing through the closed system of a turbine installation takes about 1¾ hours from the time it leaves the last stage of the turbine to enter the condenser until it re-enters the turbine again at the first stage. The time the steam takes to pass through the turbine and do its useful work is about eight-hundredths of a second. The gain in kinetic energy due to adiabatic expansion of steam in a nozzle is equal to the " heat drop " between the initial (stop valve) and final (condenser inlet) conditions of the steam. The interpretation of the physical laws under which the de-energisation of steam takes place in the turbine may be shown by means of the Mollier diagram. Although steam pressures

and temperatures vary over a wide range, the heat content remains fairly steady (Table 42) and the selection of steam conditions is therefore influenced to only a small extent by their heat-content values.

TABLE 42. *Steam Data*

Heat Content B.Th.U.	Entropy	Pressure lb. per sq. in.	Temp. °F.	Volume cub. ft.	Saturation Temp. °F.	Heat Drop to 29 in. Vacuum. B.Th.U.
1370	1·60	630	725	1·08	493	511
	1·65	390	703	1·72	443	484
	1·70	242	688	2·75	398	457
1410	1·60	850	810	0·85	527	551
	1·65	535	790	1·35	476	524
	1·70	345	774	2·18	431	497
1450	1·60	1,130	900	0·69	562	591
	1·65	720	874	1·12	509	564
	1·70	445	859	1·75	457	537

The efficiency of the heat-engine depends upon the initial temperature at which heat is taken and the temperature at which heat is rejected and may be represented by the expression $\frac{T_1 - T_2}{T_1}$, where T_1 is the absolute initial temperature and T_2 the absolute final temperature.

Referring to steam tables it will be observed that a large proportion of the total heat is latent heat and this heat is absorbed during the process of evaporation. To enable this latent heat to be taken in at a high temperature, it follows that the steam pressure must be high, and this is primarily the reason for the adoption of high steam pressures. For a given steam temperature at the stop valve and vacuum at the condenser, and for a given turbine efficiency, the moisture content on the low pressure section of a turbine increases with increased initial steam pressure. The steam thus becomes wetter at an earlier point in its expansion through the turbine. This will be apparent on referring to the Mollier diagram and noting the saturation line. The fundamental features may be summarised as follows :—

(1) Increasing the initial steam pressure (stop valve) with a given constant steam temperature *increases* the moisture in the exhaust (condenser inlet).

(2) Increasing the initial steam temperature with a given constant steam pressure *decreases* the moisture in the exhaust.

(3) Increasing the vacuum at the exhaust *increases* the moisture.

As the turbine efficiency is increased the moisture in the exhaust increases for given steam conditions. The use of multi-stage bled steam feed-heating assists in reducing the wetness in the exhaust as a certain amount of the moisture formed can be carried away through the low-pressure bled steam pipes.

This increased moisture content in the low-pressure stages has a detrimental effect on the blading due to erosion and the turbine efficiency is also impaired. The use of very high-pressure steam

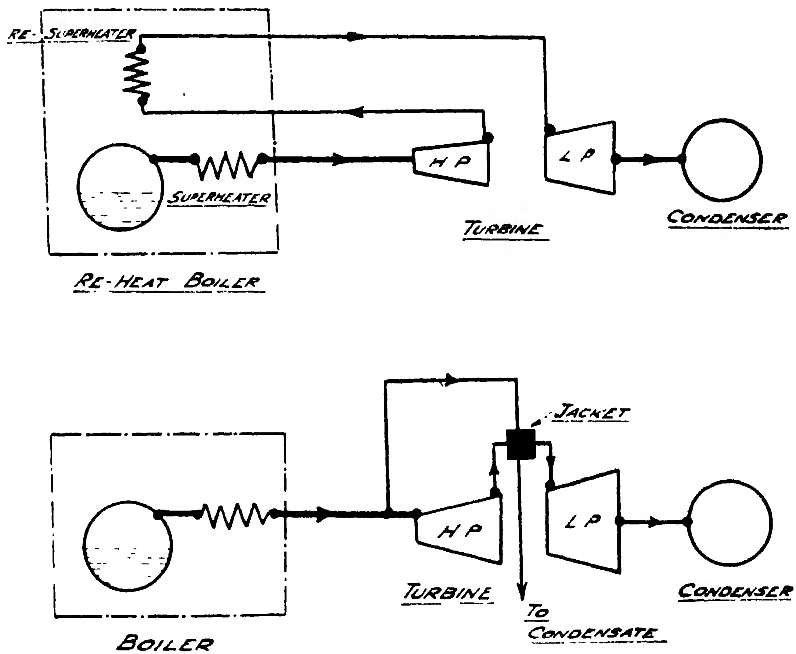


FIG. 272. Methods of Re-Superheating.

entails the inclusion of special re-heating plant between the high-pressure and low-pressure cylinders to limit the moisture in the steam in the lower stages or alternatively raising the initial temperature by superheating. This minimises erosion troubles and is now common practice. It is accomplished by superheating at the boiler or re-superheating after partial expansion in the turbine. The latter method has been used and appears to be giving satisfaction even with a pressure of 625 p.s.i. and 850° F. temperature. It shows only a small thermal gain and involves certain plant complications with additional capital costs particularly where re-super-

heating is carried out in a special boiler usually termed a "Reheat Boiler" (Fig. 272). One station in this country operates on the reheat cycle with steam at 1,235 p.s.i. and 825° F. reheated to 825° F., having two boilers per turbine on the unit principle. If the turbine is suddenly unloaded the re-superheating system acts as a steam accumulator and it is quite possible that the energy available will be sufficient to over-speed and trip the set off the bus-bars. Further, the sudden reduction in load on the re-superheater may result in burning out the tubes. To safeguard against these contingencies automatic protective devices in the form of overspeed emergency valves for the low-pressure turbine and damper control of the flue gases in the re-heater boiler are installed. An alternative method is to jacket the steam between the high-pressure and low-pressure cylinders and pass steam at the high-pressure conditions through the jacket. This may be carried out by using the high- and low-pressure cylinders of a single turbine or by having two independent turbines, one operating at high-pressure steam conditions and the other at low pressure. The H.P. turbines will exhaust at a pressure equivalent to the inlet pressure of the L.P. turbines, the steam being subject to re-superheating before passing on to the latter sets. Fig. 273 shows the arrangement for one small plant used as a topping set (see also Fig. 8).

The efficiency of a large turbine with feed heating may approach 86 per cent. One of the primary factors in the attainment of high efficiency and economy of steam is to allow the turbine to operate at the most suitable velocity ratio, *i.e.*, the ratio of mean blade velocity to steam velocity. To get the best mechanical effect the velocity which the steam acquires in its expansion must be related to the speed of the blades. The condition for maximum blade efficiency is given when the mean blade speed is equal to half the tangential component of the steam jet velocity issuing from the nozzle. The turbine efficiency is therefore largely a matter of the relation of blade speed to steam speed, or, more conveniently in the case of a multi-stage turbine, of the ratio :—

$$\frac{\text{Sum of the squares of blade speeds}}{\text{Heat drop}}$$

and within the limits of ordinary design this ratio has to be kept as high as possible if a good efficiency is to be obtained. Examples are included to show how the efficiency of a plant is fixed by the pressure and temperature conditions chosen. Considering the theoretically ideal cycle, namely, the Carnot cycle, the efficiency of which is the

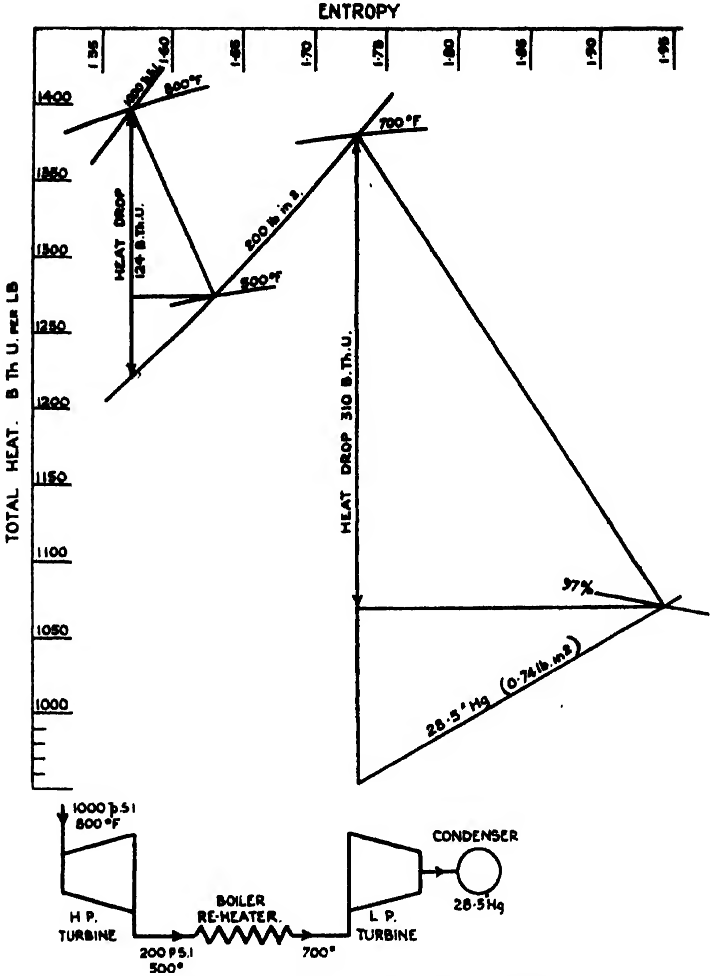


FIG. 273. Mollier Diagram for Reheat Plant.

maximum possible; the efficiency is expressed by $\frac{T_1 - T_2}{T_1}$, of which mention has already been made.

Taking four present-day examples, we have :—

(1)	300 p.s.i.	750° F.	All expanding down to 1 p.s.i. back pressure (100° F.).
(2)	450 ,,	800° F.	
(3)	600 ,,	850° F.	
(4)	1,200 ,,	950° F.	

$$(1)\quad \frac{(750 + 460) - (100 + 460)}{(750 + 460)} \times 100 = 53\cdot7 \text{ per cent.}$$

$$(2)\quad \frac{(800 + 460) - (100 + 460)}{(800 + 460)} \times 100 = 55\cdot5 \quad ,, \quad ,,$$

$$(3)\quad \frac{(850 + 460) - (100 + 460)}{(850 + 460)} \times 100 = 57\cdot2 \quad ,, \quad ,,$$

$$(4)\quad \frac{(950 + 460) - (100 + 460)}{(950 + 460)} \times 100 = 60\cdot2 \quad ,, \quad ,,$$

It will be noted that the efficiency depends upon the temperature conditions obtaining. Increase in temperature can be obtained either by increasing the pressure or by superheating the steam, or by a combination of both. As is well known, temperature is only a measure of heat. The work done per pound of steam is the result of the heat units contained therein since the temperature does no work and is merely a record of the units contained.

The efficiency might be better written as :—

$$\frac{H_1 - H_2}{H_1}$$

Where H_1 = the total heat units per lb. of steam at the initial pressure and temperature.

H_2 = the total heat units per lb. of steam at the final pressure and temperature.

By modification to the Carnot cycle for steam the Rankine cycle is obtained which is used for comparison of steam turbines.

The Rankine efficiency $= \dfrac{H_1 - H_3}{H_1 - H_4}$

where H_3 = heat units rejected per lb. of steam at the final pressure and temperature.

H_4 = heat units remaining per lb. of steam at the final pressure and temperature.

Therefore Rankine efficiency =

$$\frac{\text{Heat supplied per lb. of steam} - \text{Heat rejected per lb. of steam}}{\text{Heat available per lb. of steam}}.$$

Considering example (1)
(300 lb. — 750° F.)

$$= \frac{1{,}393 - 943}{1{,}393 - 70} \times 100$$

$$= \frac{450}{1,323} \times 100$$

$= 34 \cdot 0$ per cent., approximately.

H_1 is read direct from steam tables or alternatively from the Mollier diagram.
H_3 is read from the Mollier diagram (drop between initial and final conditions) or alternatively from special steam tables.
H_4 is read from steam tables (sensible heat).

Example (3) would give :—

$$\text{Rankine efficiency} = \frac{1,438 - 920}{1,438 - 70} \times 100$$

$$= \frac{518}{1,368} \times 100$$

$= 37 \cdot 6$ per cent., approximately.

The effect of raising initial steam pressure and temperature on the efficiency is shown in Fig. 274. The curves give the approximate performance expected with average size turbines for the steam pressure selected and assume a vacuum of 29 in. Hg. Taking an example with initial steam conditions of 800 lb. per square inch and 800° F., and reading vertically from the point 800 lb. on the base line to the 800° F. curve of the top group of curves, the turbine efficiency is found to be 82·5 per cent.

Reading on the middle group of curves again on the 800° F. curve, the possible efficiency of the cycle is found to be 40 per cent. The actual thermal efficiency for this turbine efficiency as ascertained from the 800° F. curve of the lowest group of curves would be 33 per cent. The percentage moisture in the exhaust steam is indicated on the lowest group which in the example selected is about 13 per cent. This amount would be considered excessive and except in special cases the initial temperature should therefore be raised to 850° F. if a moisture content of 12 per cent. is desired. The limiting final moisture content which is usually considered advisable is about 12 to 13 per cent., and it follows that the maximum initial steam pressure is fixed by the steam temperature proposed. Taking a turbine efficiency of 80 to 82 per cent., a vacuum of 29 to 29·1 in. Hg (barometer 30 in.) and a final moisture content of 12 to 13 per cent., it will be found that the limiting pressures with various initial steam temperatures are approximately as follows :—

Steam temperature ° F. .	750	800	850	900	950	1,000
Steam pressure lb. per square inch gauge . . .	580	750	950	1,200	1,500	1,900

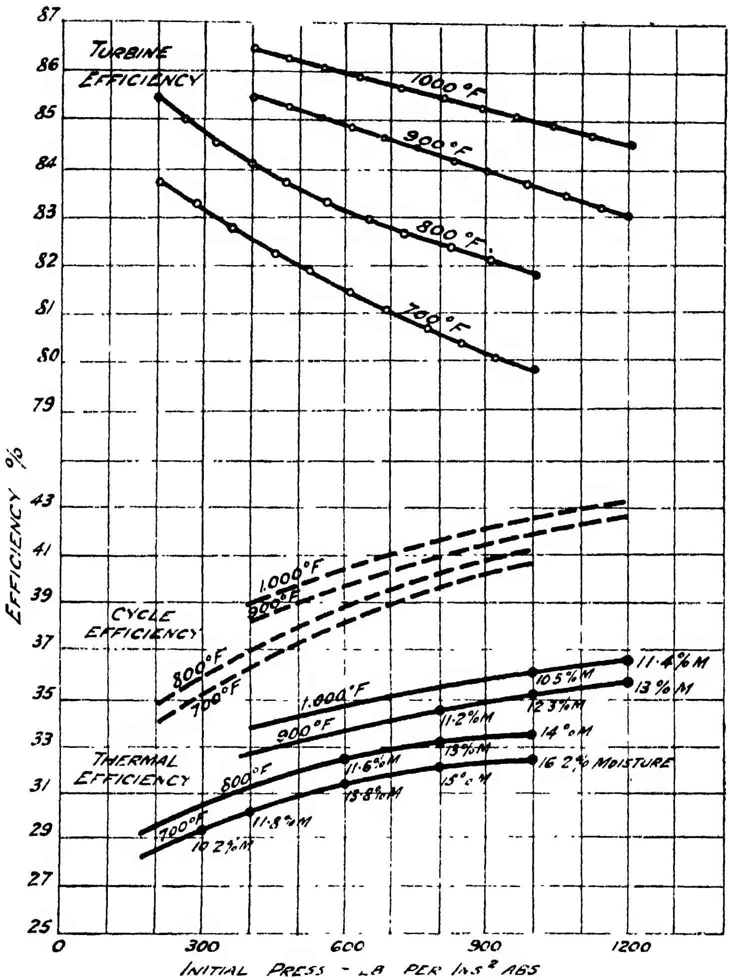


FIG. 274. Curves showing Effect on Efficiency of Raising Initial Steam Pressure and Temperature.

In this country turbines are now more or less standardised as follows :—

30 MW—600 p.s.i.—800/910°F.—Feed 340° F.

60 and 100 MW—900/1,500 p.s.i.—900/1,050 °F—Feed 380°/430 °F.

CONSTRUCTIONAL DETAILS

Casings. The H.P. casings are constructed of cast steel, the L.P. and exhaust casings of high-grade cast iron, or in certain instances of welded steel construction. The upper limit of tempera-

Keys and keyways are provided and arranged to suit the requirements of fixing for each design of machine.

The steam leaves the high pressure cylinder (14 p.s.i. or below), and is led to the low-pressure cylinder by one or two pipes fitted with expansion joints. If the pipes are arranged overhead they have to be dismantled before the covers can be removed.

Steam Chest. Steam chests are made of cast steel similar to the H.P. casings. It is essential to eliminate large external forces which might be applied to the cylinder such as those resulting from the steam pipe expansion. To eliminate such forces from the cylinder a separate steam control chest is fixed to the foundations in such a manner that the supply steam pipe forces can produce no movement of the steam chest.

Corrugated interconnecting loop pipes are fitted between the steam chest and the H.P. cylinder, and are so arranged that cylinder expansion is taken as cold spring on the pipes. This is done by assembling the loop steam pipes with the cylinder in its cold position, and the steam chest in a false position, so that no stress is applied to the loop pipes. After the joints are made the steam chest is jacked forward and outwards an amount equal to the calculated total expansion. The steam chest is then finally anchored in position. An alternative (Fig. 276) is to cast the chest in one with the top half of the H.P. casing.

Steam strainers are incorporated in the chest and adequate drains are provided. The effective area of the strainers is generally not less than twice the cross-sectional area of the main steam pipe.

The steam chest accommodates the controlling valves which adjust the steam supply to suit load conditions.

Shafts. The design of turbine and alternator spindles for large sets calls for great care if the desired degree of safety is to be ensured. The turbine spindle may be subjected to temperatures of the order of 750° to 1,050° F., in which case portions of it will reach a temperature sufficient to effect at least a partial release of any internal stress present.

With continuous application of high steam temperatures stress release becomes almost complete and in the process a bent shaft may result. It is therefore essential that the forging and subsequent machining operations of the shaft must be so carried out that no internal stresses of appreciable magnitude remain in the shaft when it is put into commission. The question of reversal of stress due to normal running and out of balance must be considered. Assuming

a turbine to operate for only 50 per cent. of the total available hours in a year and its normal rotational speed to be 3,000 r.p.m., then the shaft undergoes something approaching 8×10^8 stress reversals per annum. This introduces the problems of normal fatigue and corrosive fatigue, the latter of which depends on the steam supply. Steam, no matter how carefully the feed water has been controlled and treated, may contain some form of corrosive which, continuously applied, results in a reduction of fatigue limit. Dissolved oxygen is a

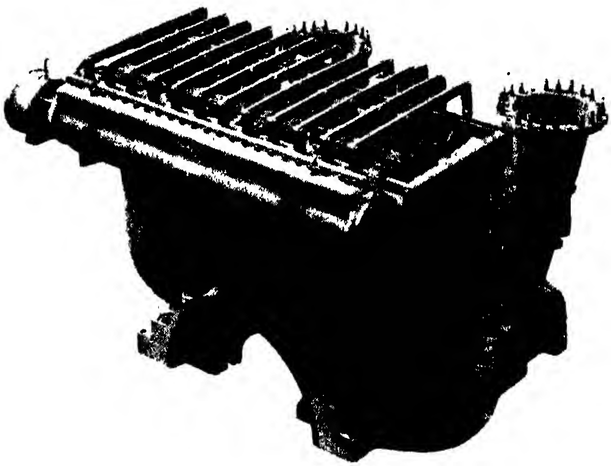


FIG. 276. Top-half Casing for High-pressure Steam Turbine with Valve Chest Cast in one with Casing. (British Thomson-Houston Co. Ltd.)

corrosive capable of doing considerable damage in boiler and turbine plant. The shaft design should be such that all sharp corners and abrupt changes in diameters are avoided. The usual practice is to turn down the shaft gradually where a reduction in section occurs, and it is advisable to fillet the shaft for there is always the possibility of fracture or cracking at these changes of section. There should be no holes or corners in which corrosive mixtures may be deposited and thus greatly increase the danger of corrosion fatigue. In practice, shafts have been bent due to various causes, and at times some success has been achieved in straightening on site. In one case the discs were protected from the heat flames by covering them with asbestos tape, etc. The shaft portions between each

disc were then repeatedly heated and cooled, which allowed the shaft to finally take up its normal straight position. The heating was done by means of gas jets. Local heating causes the metal to take a permanent set at this particular point due to the restraint of the cold metal round it. The difference in the stress-strain characteristics at widely different temperatures makes this possible. On cooling the treated metal retracts from a new point on the curve, and the shape of the whole is consequently different from what it was before. In any job of any size or importance the complicated residual stress is always a problem, as is the eventual effect of its readjustment. Shafts are made of high-grade carbon steel of adequate proportions to ensure safety under any abnormal overloads due to short circuits, etc. The shafts usually have a 2- to 4-in. diameter hole drilled or trepanned down the centre, so that the forgings can be carefully checked for any defects by means of a borescope. The specification covering the manufacture of the forgings is very comprehensive and research still continues in the question of procedure to be followed.

The principal features of one specification are :--

(1) From the pouring of the ingot until all forging operations are completed, the steel at no time falls below 650° C.

(2) At no time during the forging operations must the steel be charged into a furnace which has a temperature more than 50° C. above or below the temperature of the forging.

(3) Every practicable step must be taken to obtain uniform heating and cooling of the mass, and this particularly applies where a change of section is considerable, such as at the shaft ends.

Rotor bursting has been experienced, and in one case wrecked the station and resulted in the loss of several lives. Subsequent investigation revealed the presence of numerous cracks, situated about midway between the outside and the centre. It was concluded that these cracks had been formed as the result of thermal stresses set up during the manufacture of the forging ("Turbine and Electrical Rotor Forgings," J. C. M. Turnbull, *Heaton Works Journal*, Vol. 5, No. 3, 1950). This shaft had been made during the period when mass effect was neglected, and had been forged from a cold 78-in. octagon ingot, which was charged into a hot furnace for heating prior to forging.

Air-hardened steels are chiefly used for both turbine and electrical rotor shafts, as it is the opinion that many manufacturing hazards are avoided. It is probable, however, that the limit of strength obtainable with normalised carbon or low-alloy steels in large

masses has almost been reached and that some type of oil-hardened steel will have to be considered in future if design stresses rise much further. This step, although not altogether desirable, may be taken with confidence, due to the many advances which have been made both in steelmaking practice and in inspection methods.

The portion of the forging most likely to contain unsound metal is the centre of what was the top end of the ingot, and, in addition to discarding a large proportion of the ingot top before forging, that end of the shaft which will undergo the least stress in service should be made from the top of the ingot. The diameter of the shaft is usually such that the critical speed does not come within 30 per cent. of the running speed. The critical speed of a shaft has been defined as that speed at which a very small eccentric mass will cause the shaft to deflect to a very great extent. This speed coincides with the natural frequency of vibration of the shaft and also it is at this speed which any accidental deflection of the shaft results in a centrifugal force due to its rotation about a position of rest, sufficiently large to maintain this deflection. Hollow construction results in rotors of relatively light weight and high critical speed.

Some details of typical shafts are given.

Two cylinder impulse turbine (50 MW, 1,500 r.p.m.).

Minimum diameter of shafts	$10\frac{1}{2}$ in.
Overall length of H.P. shaft	16 ft.
,, ,, L.P. ,,	20 ft. 6 in.
Critical speed of H.P. rotor	2,100 r.p.m.
,, ,, L.P. ,,	2.000 ,,
Overspeed test	1.725 ,,
Duration of overspeed test	5 minutes.

Three cylinder impulse reaction (30 MW, 3,000 r.p.m.).

	H.	I.	L.
Minimum diameter of shafts	3 in.	$4\frac{3}{4}$ in. and $5\frac{3}{4}$ in.	
Overall length of H.P. shaft		11 ft. 1 in.	
,, ,, I.P. ,,		10 ft. 8 in.	
,, ,, L.P. ,,		15 ft. 2 in.	
Critical speed of H.P. rotor	3,930 r.p.m.		
,, ,, I.P. ,,	3,935 ,,		
,, ,, L.P. ,,	3,980 ,,		
Overspeed test	3,450 ,,		
Duration of overspeed test	Not exceeding 5 minutes.		

Fig. 277 shows a typical deflection curve for the shafts of a two-cylinder set. The shafts must be aligned to follow the natural deflections of the individual shafts and form a continuous curve. The shafts retain their natural deflections at whatever speed they

by machining from solid bar, be drop forged, extruded or rolled, rolling being considered the best method. As already mentioned, the area through the exhaust blading fixes the output of the turbine and must therefore be sufficient to handle the volume of steam efficiently. The tip diameter of the blade ring fixes the area available and the permissible stresses in wheel and blade in turn fix the tip diameter. To reduce centrifugal stress in the blades it is general practice to taper them so that the cross-sectional area decreases

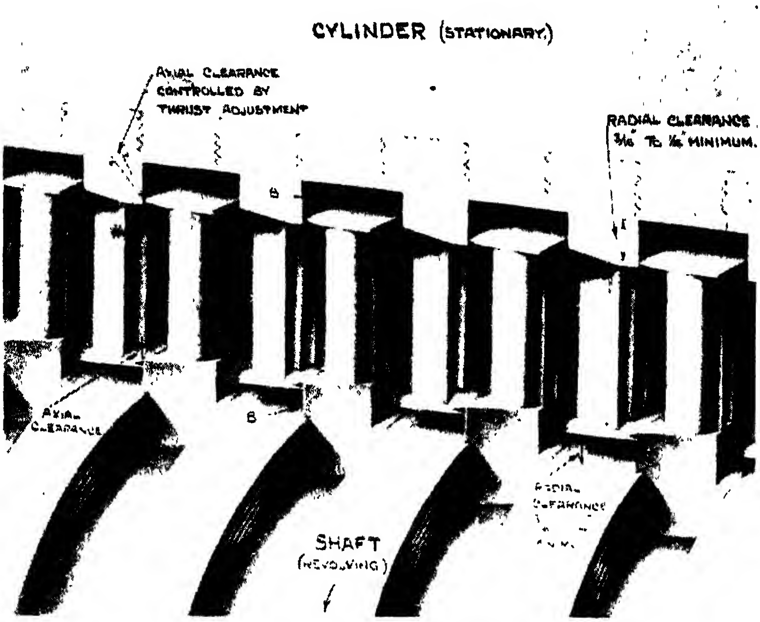


FIG. 279. End Tightened Blading The blade roots, instead of being flush with the surface of the casing and rotor, are raised up to form circumferential barriers BB. (Direction of steam flow →) (C. A. Parsons & Co. Ltd.).

steadily from the root to the tip. The greater the degree of taper the more can the stress be reduced. Because of the very definite limit to the variation in blade passage between root and tip imposed by considerations of blading efficiency it is not desirable to make the ratio between the blade height and shaft diameter greater than 1 : 3, so that for a blade tip speed of 1,000 ft. per second the maximum output possible from such a last row of blades at any specified turbine r.p.m. is limited. The output at a given number of revolutions per minute can only be increased by increasing the blade

tip speed, but the stress at the blade root for a tip speed of 1,000 ft. per second is about the limit, although tip speeds of 1,150 ft. per second have been adopted.

The use of a hollow blade at the exhaust end has made possible an increase in output of about 20 per cent. Hollow blades enable

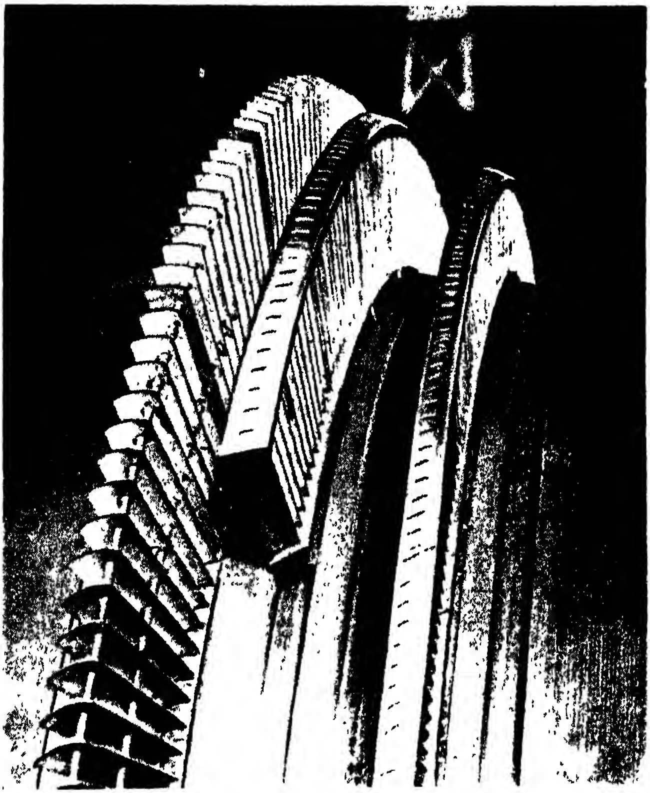


FIG. 280. Fixing Segments of Blades. The segments are serrated along their roots by means of locking strips. (C. A. Parsons & Co. Ltd.)

both blade stress and wheel stress to be reduced for a given tip speed, *i.e.*, the tip diameter can be increased without encroaching on the safety factor. To roll a hollow blade a hole is made through the stainless steel billet, the shape and size of the hole being determined by the amount of metal it is desired to remove from the finished blade. It is then filled with a tight-fitting mild steel plug and the billet is rolled in a similar manner to the rolling of solid blades. In the process the plug rolls out to a profile like that of the

blade. The mild steel can be dissolved out by a chemical treatment which does not affect the stainless steel.

Another problem influencing the design and manufacture of exhaust end blades is the erosion which may result from impact of water on the blades. With high-pressure steam conditions the wetness factor at the exhaust is high and the water thrown off from the fixed blades is moving at a velocity which is only a fraction of that of the steam. Consequently the moving blades, travelling at relatively high speeds, have to move through a dense mist of water particles which results in rapid wear of the leading edges. Erosion increases rapidly with increased blade speed, with reduced back pressure and with increased wetness, but is reduced almost in direct proportion to the increased hardness of blading material. A blade capable of meeting the erosion problem consists of an ordinary blade having a shield welded or brazed to the leading edge. The blade proper is either of low carbon stainless steel or a low carbon good quality mild steel with a very hard shield of specially heat-treated high-speed tool steel.

The shield need only extend from the blade tip to about two-thirds of the blade length, since the portion near the root is not ordinarily subject to erosion and it is therefore unnecessary to protect it. In one make of blade the portion likely to be affected is of "Stellite" steel and is deposited electrically. The advantage claimed for this method is that a better blade profile is obtained after machining. Table 43 gives blade particulars for some turbines. Figs. 279 and 280 give blade arrangements.

Alternator rotor vibration has been thought to be responsible for blade fatigue or at least aggravating conditions. In one case, a number of L.P. rotor blades on the first row (alternator end of two-flow rotor) failed and caused considerable blade damage. Investigations into the vibrational characteristics indicated that the blades were slightly sensitive and probably failed due to prolonged running when subjected to vibration. New blading was provided with stronger lacing wires of greater length to remove the blading further from the sensitive region.

Carryover from boilers may cause deposits on the blading, and so reduce the turbine output. A 30 MW set which had only been in service for one year would only do 28 MW due to this. After applying saturated steam (together with compressed air for cooling) the 30 MW output was obtained.

A small connection may be provided so that a regulated quantity of water may be introduced into the main steam supply after the

TABLE 43. *Turbine Blade Data*

Type of Turbine	Impulse Reaction. 3 Cylinder 30 MW, 3,000 r.p.m.			Impulse, 2 Cylinder 50 MW, 1,500 r.p.m.	
	H.P.	I.P.	L.P.	H.P.	L.P.
Number of stages	15	9	10 Double flow.	28	16 multi-exhaust.
Max. blade length, in.	4·07	9·52	14·87	2·80	24
Max. blade speed, ft. per sec.	441	629	901	375	705
Max. stress at blade root, tons per sq. in.	2·68	6·47	10·0	5·0	6·7
Min. radial clearance, in.	0·25	0·25	0·035	0·25	0·25
Min. axial clearance, in.	0·15	0·15	0·50	0·04	0·10
Diaphragm material	Alloy steel.	Cast iron.	—	½ per cent. Mo. steel.	C.I. except multi - exhaust F.M.S.
Nozzle material	Alloy steel.	3–5 per cent. Nickel steel.	—	½ per cent. Mo. steel.	1–3, ½ per cent. Mo. steel, remainder rustless.
Blade material	Stainless iron.	Stainless iron.	Stainless iron.	Stainless.	Stainless.

Stop valve conditions : 600 lb. per sq. in. and 800° F.

isolating valve with the set running at low speed. Grit from stoker-fired boilers is not too abrasive, but is more effective than pulverised-coal fly-ash for " sand " blasting turbine blades to remove deposits.

Nozzles. The nozzles consist of segmental steel castings having high-carbon steel division plates cast in position and set at the correct angle for directing the steam against the rotating blades. The sides of the nozzle openings are highly finished to afford the least possible resistance to the flow of steam.

Diaphragms. The diaphragms containing the fixed guide vanes or blades are of cast steel in the high-pressure high-temperature zone and cast-iron in the low-pressure low-temperature zone. The vanes, which are usually of special steel, are cast in position. In the high-

pressure stages where the axial width of exit of the nozzles is small the nozzles are machined out of solid blocks of steel and fitted and secured to the mild steel centre portion of the diaphragm. In the lower pressure stages where the width of exit is large the steel division plates forming the nozzle openings are cast into diaphragms of semi-steel or cast iron. A diaphragm in which nozzle openings through which the steam passes from one wheel to the next is placed between each two adjacent wheels of the turbine except in the case of the reaction stages. The diaphragms, which are made in halves and fixed so that they lift with the casing, are provided with a socket

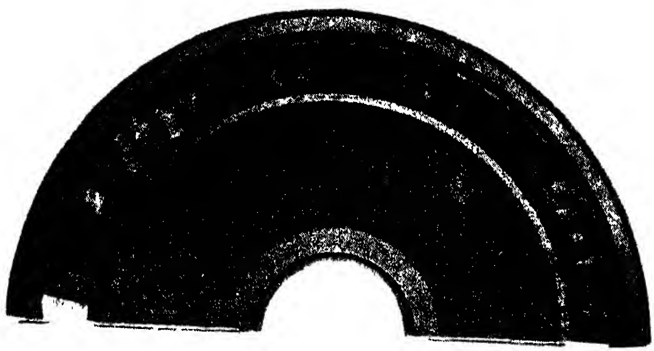


Fig. 281. Lower Half of Nozzle Diaphragm, Cast Type, for Low-pressure Stage. (British Thomson-Houston Co. Ltd.)

and spigot joint to ensure accurate alignment and to prevent leakage of steam from one side of the diaphragm to the other (Fig. 281). The central opening in each diaphragm through which the shaft passes is sealed by means of a labyrinth type of packing gland.

Couplings. Couplings are designed so that they are capable of transmitting large powers at high speeds and in addition provide a considerable measure of flexibility.

The steam rotors of multi-cylinder turbines are connected together by a coupling of either the solid or flexible type, depending on the design of the turbine (Fig. 282). Couplings of the double flexible type in which each shaft end has a toothed claw mounted on it, the two claws being connected by a sleeve, are made so that the sleeve has an extremely small radial clearance on each claw.

In some cases considerable wear has taken place between the claw faces after a number of years of service. Examination of the couplings has revealed that wear had taken place on the driving faces of the claw and sleeve resulting in the formation of steps or imprints of the claw teeth on the sleeve, thereby preventing axial movement of the alternator rotor towards the turbine. If this wear became excessive the possibility of claw fracture must not be overlooked, and the inclusion of brass or copper alloy pads with oil ways on the sleeve claws may reduce this. The reason for this is, if the coupling claw has moved out of centre due to a large radial clearance and steam is admitted to the turbine (so that the shafts

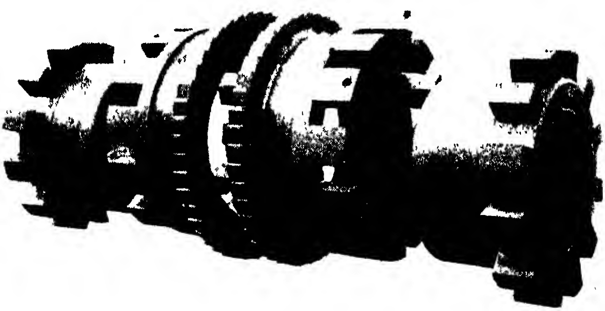


FIG. 282. Claw Type Flexible Coupling for Multi-cylinder Turbine. (British Thomson-Houston Co. Ltd.)

accelerate continuously) then the driving force will be sufficient to lock the coupling sleeve out of centre and a slight unbalance will result. A radial coupling clearance of not more than 0·005 in. on diameter has been found satisfactory, adequate flexibility being maintained.

Couplings of the single flexible type, where the connecting sleeve is rigidly bolted to a flange formed on one shaft end, however, have a very much larger radial clearance, about 0·03 in. on diameter, since the sleeve cannot become eccentric and thus upset the balance. Coupling claws are lubricated by oil ducts adjacent to the bearings from which oil is received through oil ways connected to the oil inlet. The coupling between the turbine and alternator may be of the flexible claw or the semi-flexible bellows types. The latter permits of slight movement in a transverse direction which is desir-

able in case the turbine and alternator rotors are not in exact alignment. The L.P. turbine thrust can take up axial movement from the alternator rotor.

When a machine is out of service for overhaul it is advisable to inspect the coupling keys for slackness and " steps." If the keys are " stepped " it may be that the machine has been subjected to short-circuits. It may be necessary to make new keys before re-commissioning if trouble-free operation is to be obtained.

Errors in alignment may be introduced by faults in erection or by foundation subsidence. When foundations are placed on very poor ground it is desirable to fit permanent level indicators around the foundation blocks. Coupling bolts should withstand the short-circuit stresses on test and in commercial service without permanent distortion, but should be designed to shear before any damage is done to the shaft.

Bearings. The main bearings are spherically-seated and self-aligning and consist of horizontally divided cast-iron shells lined with white metal and lubricated under oil pressure. Large diameter shafts running at high peripheral speeds are designed to remove the oil after it has passed once around the bearing surface and to introduce a new charge of cool oil just above the point of exit.

The inlet and outlet apertures are above and below the bearing joint respectively. The high-pressure oil inlets at the bottom of the bearing receive their feed from the jacking pump. Special circumferential oil grooves are included at each side of the top half to flood the bearing and so prevent ingress of air which may provoke aeration. The bottom halves are arranged so that they may be removed without appreciably raising the shaft. Supports are provided for taking the weight of the shaft when the bottom half bearings are removed. The shaft oil and water throwers are designed to prevent any escape of oil from the bearings and also leakage of any steam or water into the bearing oil wells. Any escape of oil from the main bearings may be prevented by oil guards consisting of internally grooved labyrinth rings attached to the bearing housings and closely embracing oil throwers provided on the shaft. To maintain the correct axial position of each rotor (depending on the design of turbine) a thrust bearing or block is provided, the thrust housing being mounted in the bearing pedestal.

The " Michell " type is commonly used, the bearing surface being divided over a number of pads, each being free to take up a slight angle to the plane of rotation. The oil is drawn into the wedge-shaped space so formed and the resulting high-pressure oil films

between the surfaces prevent metallic contact and enable the thrust to be floated on oil. The wear on the pads during normal operation is very small. Bridge gauges are supplied for each bearing so that the wear on the bearing may be ascertained. Vent pipes are fitted to the bearing caps to carry off oil vapour.

The oil baffles between the bearing and shaft neck gland at the high pressure end of the turbine quickly carbonise if the steam temperature is allowed to exceed the designed figure for appreciable periods. This carbonisation is a source of danger from a fire point of view, and may also cause vibration. The oil drains from the bearing should be kept free otherwise the oil baffle trouble referred to is aggravated. The oil baffle arrangement varies in design and construction but in a number of cases consists of a copper strip assembly wiping on the shaft. When carbonisation takes place to any appreciable extent, binding on the shaft, with consequent friction and vibration occurs. On occasions the carbon has been known to catch fire—a dangerous development.

Lubrication System. In view of the high speeds at which turbo-alternator shafts revolve the lubricating system becomes an important feature in their design. The rotor shafts are supported on a thin film of oil which prevents the surface of the shafts from coming into contact with the bearing. The physical properties of the oil are liable to change under high temperature and this should be maintained at a reasonable figure. Oil for lubrication should be continuous, under pressure, cool and free from injurious foreign matter. The design of the lubrication system should be carefully considered in co-operation with the turbine manufacturer and the oil supplier if a successful system is to be obtained. Cleanliness is essential in all parts of the set and system with which the oil comes in contact. Paints should not be used for bearing castings, inside of tanks, pedestals, etc.

The oil system, including all pipes, require cleaning and this can be done by charging the system with a chemical vapour which, on condensing, thoroughly cleans the pipes of deposits and reduces the bearing temperatures.

Oil Pumps. The main oil pump which is directly driven through gearing from the turbine shaft draws its supply of oil from the oil tank through strainers incorporated in the tank. In some designs the pump is placed in the oil tank, the drive from the turbine shaft being through bevel gearing. Two helical wheel pumps may be on the same drive, one giving high-pressure oil supply to the relay gear and the other low-pressure oil to the bearings.

Three superimposed oil pumps have been taken from one drive, the pumps all being immersed in the oil tank. The top pump delivers oil at a pressure of about 70 lb. p.s.i. (power oil for the governor) to the underside of the power pistons of the governor valves, the excess oil passing into the lubricating system through a relief valve. The central pump supplies oil at pressure of about 15 lb. p.s.i. to the lubricating system (machine bearings). The oil from the lower or pilot pump serves for the control of all steam valves. Before entering the system, however, this oil first passes through an emergency trip valve which is described in a later section. This valve only comes into operation in the event of the turbine speed exceeding a predetermined limit or in case the turbine driver should

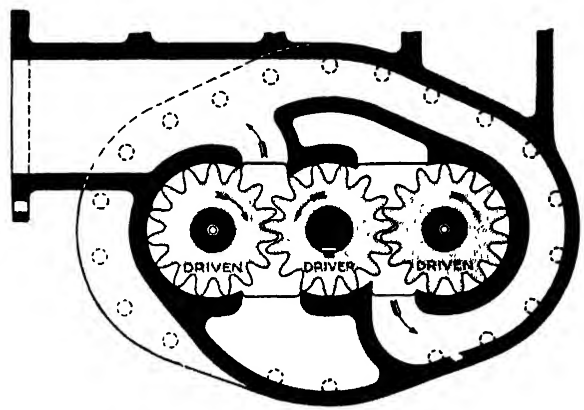


FIG. 283. Sectional Elevation of Main Oil Pump, Three-wheel Type (British Thomson-Houston Co Ltd.)

desire to stop the set in an emergency. The oil supply for the governor gear or servo-motors is taken from the pump delivery where the maximum pressure and minimum viscosity obtains.

The type of pump now fitted to large turbines consists of two- or three-toothed wheels, gearing with one another, and fitting into a comparatively small casing. The pump is driven from the turbine shaft through gearing and since there are no valves or complicated parts this type has proved very reliable. Figs. 283 and 284 show two types. To provide a supply of oil to the bearings when starting up or shutting down it is necessary to have an independently driven pump. This auxiliary pump, Fig. 284, is driven by a small steam turbine, the pump being submerged in the oil tank. The pump is also arranged for automatic operation in the event of failure of the main mechanical oil pump. The steam supply to this turbine

is controlled automatically by the oil pressure in the lubricating system so that when the main turbine slows down the auxiliary pump will start and continue to supply oil to the bearings until the master steam valve is closed. To allow of operating the auxiliary oil pump for purposes of testing and overhauling the emergency stop valve and governor valves when the set is shut down it is possible to provide an alternative steam supply from an auxiliary range. Alternatively, the by-pass valve on the main steam receiver can be used.

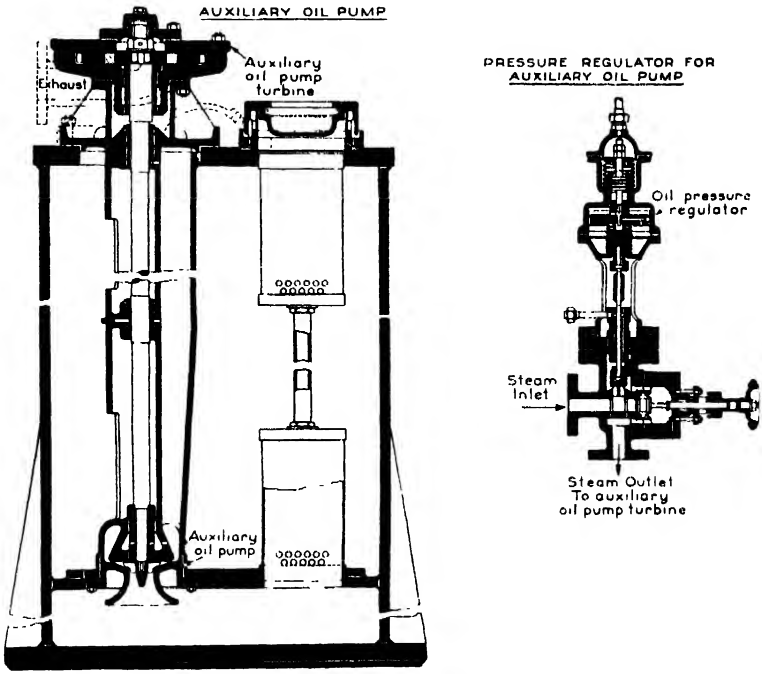


FIG. 284. Sectional Elevations showing Assembly of Auxiliary Oil Pump and Pressure Regulator for Pump. (British Thomson-Houston Co. Ltd.)

The oil from the main and auxiliary pumps is at a considerably higher pressure than that required for lubrication purposes and is therefore passed through a reducing valve to obtain the desired pressure. Venting connections on this pump should be watched to avoid air locks and a hand pump is useful for the top bearing during running up. A small steam turbine can be arranged to drive a combined gear and centrifugal pump which is used when starting and stopping the main turbine or in an emergency. As in the case of the main gear oil pumps (on main turbine shaft—one for lubri-

cating and one for relay oil), the gear portion supplies oil at a pressure of 70 p.s.i. for operating the relay valve gear and also feeds the

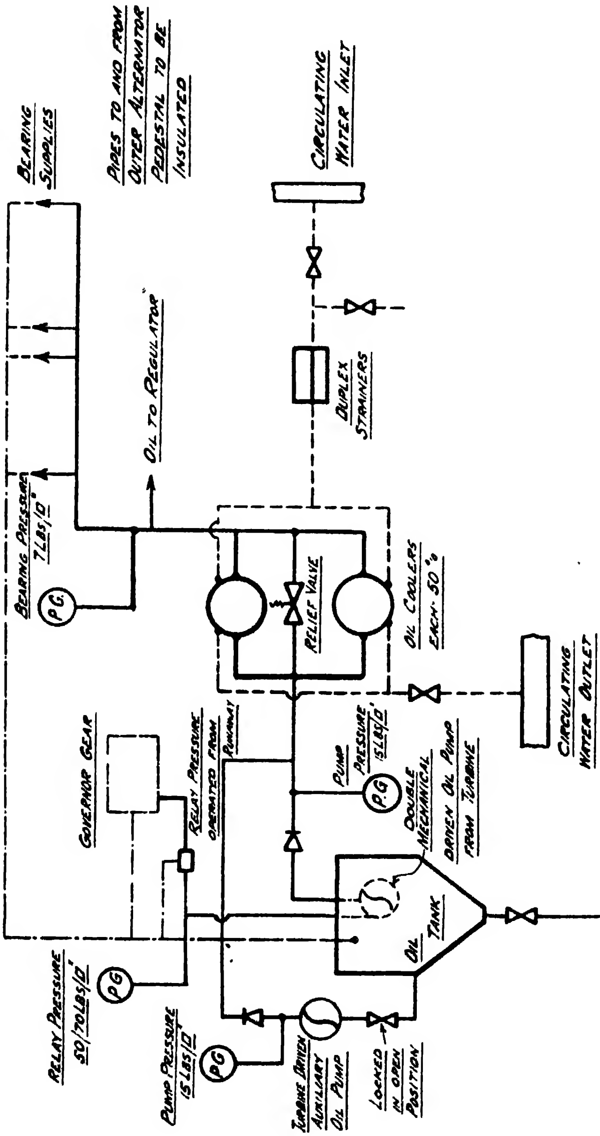


FIG. 285. Typical Lubrication System for 10 MW and 20 MW Turbo-alternators.

alternator seal system. The centrifugal pump delivers oil at pressure of 15 p.s.i. for lubricating the bearings and thrust blocks. This pump is controlled by a regulator which automatically starts when

the bearing oil pressure falls below a predetermined value. In order that the pressure drop across the oil coolers shall not become exces-

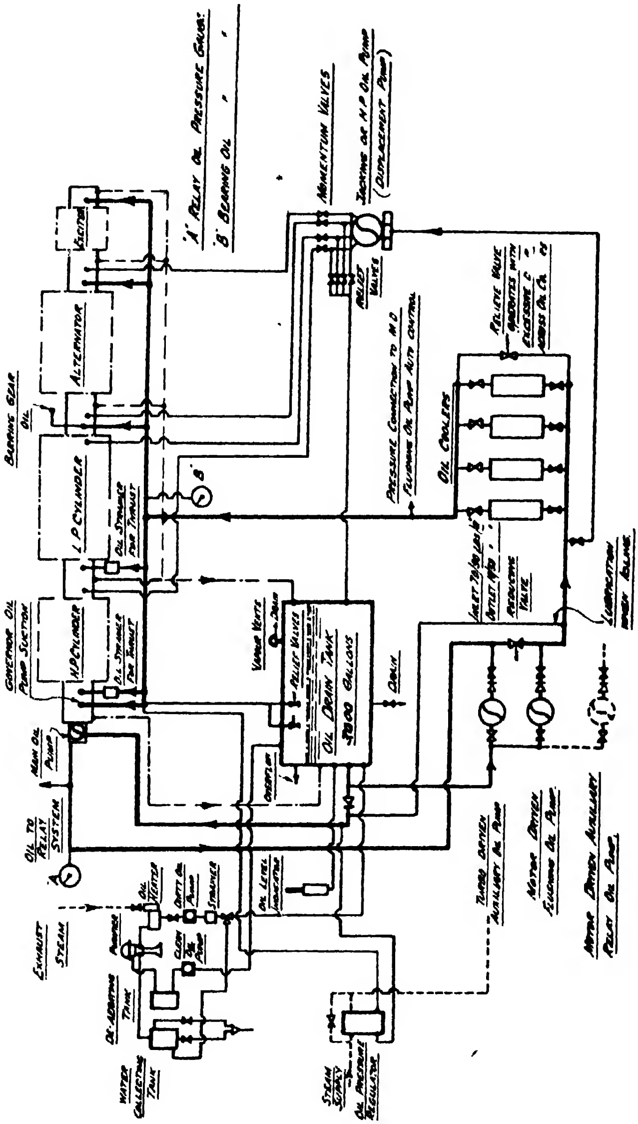


FIG. 286 Diagrammatic Arrangement of Oil System for 50 MW Turbo-alternator.

sive when starting up from cold, a spring-controlled relief valve by-passes some of the oil from the inlet to the outlet of the coolers.

When starting up the set, steam is first of all turned on to the

auxiliary oil pump, and it commences to deliver oil to the bearings, being cut out automatically when the set has reached normal running speed. This pump supplies the oil for priming the bearings when starting up or shutting down.

Various forms of automatic regulating valves are in use, and they sometimes suffer from valve stickiness and may cause nuisance due to oil leakage. The standard arrangement comprises an automatic regulator valve which acts as a reducing valve and in addition a throttle plate may be fitted in front of the turbine nozzles for reducing the pressure (possibly 400 lb. on a 600-lb. steam supply).

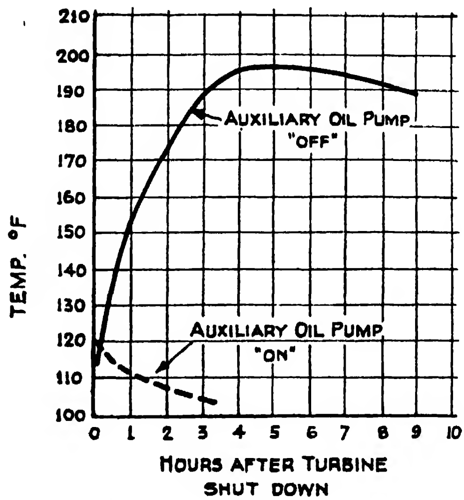


FIG. 287. Bearing Temperatures with and without Oil Pump.

The size of hole in the plate is adjusted on site until the pump gives the desired oil pressure. The steam pressure may be hand controlled, the pump being placed on the operating floor, but there are stations where it is in the basement. In the former position the turbine driver is responsible for its operation, whereas in the latter it is under the control of the auxiliary plant attendant. This is only a small point but it may give rise to discussions on the division of labour in the station. Where a reliable and independent source (preferably from the station battery) of auxiliary supply is available it may be justifiable to dispense with this turbine-driven auxiliary oil pump and substitute a motor drive. A further alternative is to have a combined turbine electric-driven pump which incorporates the usual automatic features. In some installations there are two

a.c. motor-driven oil pumps and should No. 1 pump fail, No. 2 pump is then started automatically. To guard against failure of a.c. supply, No. 3 pump (d.c.) is started automatically. Reserve supplies of lubricating oil may be stored in small oil vessels placed immediately over each bearing. When barring gear is fitted it is necessary to include high- and low-pressure oil pumps for jacking and continuous cooling of the bearings. Where barring gear is not fitted it is sometimes advisable to run the auxiliary oil pump for some considerable period after the turbine has stopped to avoid local high oil temperatures. This may necessitate an auxiliary turbine designed for prolonged operation or trouble may be experienced from turbine failures.

Figs. 285 and 286 show two typical oil systems, and Fig. 287 illustrates the bearing temperatures with and without the oil pump in operation.

Oil Coolers. To ensure that the oil is cooled to a suitable temperature coolers are provided, the cooling surface required depending upon the temperature of the water used. The coolers may be placed in the basement immediately below the turbine, or alternatively mounted on an intermediate platform. Some engineers contend that the oil tank should be the lowest point in the lubricating system and not the coolers as in many installations. The design and layout of the coolers should permit of easy access to the tubes for cleaning. The cleaning of the oil side, *i.e.*, the outside, of tubes may be done with a degreasing agent such as trichlorethylene (bearing temperatures have been reduced 20° F. after such treatment) or alternatively by immersing the tube nest in a solution of caustic soda, caustic potash or sodium carbonate. After treatment it is essential to remove all trace of the cleaning solution. This may be done by means of a steam jet with repeated washings with clean water as a final precaution. The tubes should not be tinned on the inside. Drain valves should be fitted on both the oil and water sides of the coolers, although it is possible to dispense with the water-space drains in some layouts. The pipework to the coolers should be arranged so that any cooler can be removed when the set is running. Vertical coolers are used as any sludge will fall to the bottom, and to assist this precipitation the oil should enter the coolers on the top. The cooler water inlet would then be at the bottom and contra-flow would ensure good cooling. The oil pressure in the coolers should be maintained at a higher value than that of the cooling water to prevent leakage of water into the oil system. Even so it is possible for small quantities of water to be injected

into the system. Under normal working the cooling water is taken from the circulating water system, but in cases of emergency may be taken from some other source, *e.g.*, the town main or reserve tanks. The general opinion is that oil should never exceed 140° F. for prolonged periods. A uniform normal oil temperature protects the bearings and reduces likelihood of moisture condensation in the oil system. The quantity of air in vapour spaces of the oil system may be held to a minimum by means of an exhauster. In some cases high local heating or hot spots in the bearings or relay and pump gear appears to have been responsible for deterioration of the oil. With large sets it would appear that a maximum temperature of 130° to 150° F. is desirable if the oil is to be maintained in good condition. Test results show that increase in the oil velocity is more effective in raising the overall rate of heat transmission than the corresponding increase in the water velocity, but care is needed regarding the pressure drop across the cooler, especially on the oil side. High velocities under working conditions involve heavy pressure drops at starting when the viscosity of the oil may be three to six times as great, and special fittings, such as spring-loaded by-pass valves across the cooler, may be necessary to avoid overloading the oil pump.

In some designs the oil flows over the tubes at between 80 to 100 ft. per minute and the water flows through the tubes at about 30 ft. per minute. When cooling heavy medium turbine oil the heat transmission rate at these velocities is between 35 to 40 B.Th.U. per hour per sq. ft. per ° F.

Flexible Couplings. To reduce wear an oil supply is provided, suitable grooves being included to distribute the oil over the driving face.

Strainers. These may be arranged in the oil tank or alternatively at the suctions of the pump and should permit of cleaning and inspection whilst the plant is running. A fine strainer made of brass gauze is sometimes arranged inside a coarse perforated sheet steel strainer.

Oil Tank. This should be capable of holding an ample supply of lubricating oil and in addition may be designed to incorporate the oil strainers. The tank is generally constructed of boiler plate made up in the form of a hopper. This enables water in the oil system to settle out and be drained off. In the detailed design of an oil tank the following points are worthy of consideration :—

(1) All manhole doors and other openings should be perfectly oil-tight. A good jointing material is essential.

(2) Easy access should be provided to all internal passages and fittings to facilitate cleaning.

(3) Pockets should be avoided where water is likely to collect.

(4) Large drains should be provided for the removal of oil and sludge.

(5) The return oil pipes to the tank should have their outlets below the working level of the oil to prevent spraying of oil.

(6) Arrangements should be made for filling, emptying and sampling of oil.

(7) Suitable vapour outlets should be provided.

The auxiliary pump may be placed inside the oil tank or alternatively a connection taken to it from the tank. The tank should be kept as far away as possible from steam pipes to minimise the risk of fire. Oil tanks have been placed outside the buildings on this account. The usual place is just below the operating floor and the flooring immediately above should be removable to give access. Adequate vent or vapour outlets should be provided on the oil tank and be brought up above floor level, for if they discharge to the underside of the floor the surrounding area becomes coated with oil.

The outlets should have cowls and collecting trays with drain pipes leading back to the oil tank. An alternative is to turn the vapour outlet into a tundish below floor level. Baffles welded into the pipe prevent oil throwing. Oil should be periodically drawn off from the bottom of the oil tank to remove any water or sludge which may have settled. The rapidity of circulation may have some effect on the deterioration of an oil, and in order to limit the rate of circulation the oil tank should be as large as possible. The total quantity of oil in the system bears a definite relation to the pump capacity, namely,

$$\text{Changes per hour} = \frac{Q \times 60}{C}$$

where Q = the pump capacity in gallons per minute.
C = capacity of oil in system in gallons.

It has been suggested that the number of changes per hour should not exceed 6 to 10, even if highly refined oils are used. The changes per hour for some sets can be estimated from the figures given in Table 44. The air and water have a better chance of separating from the oil in a large tank thus enabling the oil to function under the best possible conditions.

Oil Purifiers and Filters. A motor-driven centrifugal oil purifier, pump, heating apparatus, de-aerating tank and other fittings are included. A given amount of oil is drawn continuously from the oil tank, passed through the purifier and returned to the system. In this way the complete filling of oil is subject to purification, any

TABLE 44. *Oil System Data*

Type of Turbine	M.C.R Rating MW	Oil Cooler Surface square ft.	Total Cooling Water g.p.m	Relay Oil Pressure lb. square in	Bearing Oil Pressure lb. square in.	Oil Tank Galls.	Oil Purifier g.p.h	Temp. of Cooling Water °F.	Oil circulated g.p.m.
Reaction 1 cylinder	10	2 190	78	50/70	7	260	30	60	80
Reaction 1 cylinder	20	2-550	134	50/70	7	390	30	60	135
Impulse reaction 3 cylinder.	30	3-920 1 spare	500	50	7/15	1,500	200	90	270
Impulse reaction 2 cylinder.	30	3-312 1 spare	266	60	7/15	1,500	200	90	250
Reaction 2 cylinder	30	3-310 1 spare	174	70	7/15	720 1,000 in system	110	60	180
Impulse 2 cylinder	50	4-368 1 spare	300	70/90	10/30	3,000 3,700 in system	400	90	400
Impulse 3 cylinder.	75	4 1 spare	300	80	10	1,200 3,600 Total.	200	75	436
Radial flow	16/20	3 82 1 spare	180	55/60	7½	600	100	60	125
,, ,,	30	3-170 1 spare	322	55/60	6½	1,200	200	80	322
,, ,,	50	3-230 1 spare	350	55/60	6½	1,500	250	60	422
Impulse reaction 2 cylinder.	30	3-580	520	40/60	10/15	1,500 1,800 in system	500	85	270

water and sludge being removed. When the purifier is shut down the bowl should be self-draining for if water and sludge remain in the bowl and are slightly acid, corrosion will take place. It is found that the purifier discs indicate the presence of oxide deposits and this may be minimised by changing the sealing water on alternate days. Replacing the water seal in the bowl reduces the accumulation of acid materials. In some cases an oil filter is included and the oil is extracted continuously from the delivery side of the oil pump, filtered, and returned to the system. The purifier and filter should be placed on the operating floor preferably near the oil tank.

The output of the purifier varies according to the size of the set and the opinions of the engineers responsible for the installation of the plant. An oil system of 1,000 gallons with a purifier of 100 g.p.h. will be completely circulated through the purifier once every 10 hours.

Filtration of lubricating may be carried out in a central purifying house, instead of the more general system of separate filtration for each machine. Under the centralised system the oil filtered is drawn from one machine at a time.

Oil Pipework. The oil pipes should be of solid drawn steel, attention being paid to all joints and jointing materials, for oil under pressure is very penetrating. Although control valves may be used, they are not recommended, since it is possible for one to be left in the closed position. Nozzle plates can be fitted in the bearing supply pipes and are preferable, the size of nozzle being determined when putting the set into service. Each return pipe should be fitted with an oil box so that the flow of oil from each bearing may be observed and the temperature taken. In certain portions of the pipework small copper pipes may be used. All oil pipes should be kept away from steam pipes and when this is unavoidable the steam pipes should be arranged to pass over the oil pipes to minimise the fire risk due to oil falling on the steam pipes. Some makers have suggested and tried the use of an oil pipe within a pipe to prevent spraying of the oil and possibility of fire in the event of a relay pipe fracturing. The oil service can be arranged on the side of the machine remote from the steam supply, with the unavoidable exception of the oil pipes to the relays and the emergency valve and throttle valves. Every precaution is taken to eliminate fire risk arising from accidental oil leakages. The oil pipes subject to pressure can be mounted inside a large drainpipe or trough ; even the oil drainpipes, when they cross the steam main they can be mounted in a concrete trench to prevent accidental dripping of oil on hot parts. It would appear desirable that all steel pipes should be annealed after being in service for a few years as hardening takes place due to vibration during the running periods. Branch oil pipes leading from the bearing pedestals to the main oil pipes are polished. The sludging of oil has been attributed to the presence of copper in lubricating pipes as it acts as a catalyst to the formation of sludge, particularly when associated with aeration and high oil temperatures. To avoid heating of bearings due to induced currents the outside end bearing of the alternator, the oil pipes and any lead-covered or wire-armoured cables connected thereto, should be insulated from the bed plate.

TABLE 45. *Oil System Auxiliaries*

Unit	Type	Drive	B.H.P. Rating	
			30 MW set	50 MW set
Main oil pump .	Toothed wheel.	Gear—Main shaft.	—	—
Auxiliary oil pump	Centrifugal	Auxiliary turbine	—	—
Flushing „ „	Centrifugal	Motor	2½	11
Jacking „ „	Piston-displacement	„	8	5
Relay „ „	Centrifugal	„	—	10
Oil purifier .	Centrifugal	„	2	2
Jacking oil pump (alternator only).	Piston-displacement	„	1½	—

General Data. Particulars of lubrication systems for a number of turbo-alternators are given in Tables 44 and 45.

Regarding the 75 MW set in Table 44, the oil-settling tank on the basement floor has a capacity of 1,200 gallons. The total quantity of oil in the system is about 3,600 gallons, which includes that in the settling tank and the de-aerating and collecting tanks. These are located just below the turbine-operating floor, and the return oil from the bearings is delivered into them before flowing down into the 1,200 gallon oil settling tank. The coolers are of special design and the surface cannot be compared with that of the usual type of coolers. Each cooler is designed to cool 3,600 gallons of oil per hour from 130° F. to 110° F. The relay oil pressures given in Table 44 are the maximum figures and are really the pump pressures, *e.g.*, in the case of the radial flow machines (55 to 60 p.s.i.) the pressures in the relay cylinder are between 23 to 24 p.s.i. when under control of the governor.

The capacities of the auxiliary oil pumps for 30 MW and 50 MW sets respectively were as follows :—

Turbine-driven pump	156 g.p.m.
Motor-driven flushing pump	120 „
Turbine-driven pump	400 „
Motor-driven flushing pump	300 „

Barring Gear. Barring equipment, as its name implies, is a turning or rolling gear for slowly rotating the shafts of the turbo-alternator and is on the lines of similar gear used in rolling mill practice.

The barring gear serves a number of purposes, namely :—

(1) To start the set from rest without the use of steam, so bringing about a saving of valuable time in cases of emergency.

(2) To rotate the shafts slowly when steam has been cut off, thus preventing any permanent set or bending due to uneven contraction which may occur if allowed to cool off whilst stationary. Ensures even cooling off of the turbine rotors after set is shut down and enables it to be restarted quickly in emergency at any time after shutting down without risk of vibration.

(3) Minimises possibility of shaft distortion at starting, due to unequal heating caused by inrush of steam.

(4) Maintains an oil film between the bearings and shaft journals which may cease to exist due to vaporisation.

(5) To protect the turbine blading and avoid severe temperature stresses in the valve chest and cylinders. It renders unnecessary the sudden admission of a large quantity of steam at a high temperature and pressure to start the turbine from rest.

(6) To turn the rotors for inspection purposes.

When barring gear is only fitted for the purpose of turning during inspection a manually operated type can be included. With electrically operated barring gear it is necessary to provide inching contactor starters to enable inspection of the rotors to be carried out. The " inching " or " start " and " stop " stations can be fitted at convenient positions on the turbine bedplate. In some machines the speed of the rotors during barring is very low, in the region of 1½ to 2 r.p.m., in which case " inching " control is quite unnecessary. Some makers contend that " inching " subjects the bearings to repeated knocks which in time may give rise to damage, consequently they prefer to fit a manually operated gear to be used for inspection purposes only. Some makers do not consider barring gear essential in the operation of turbo-alternators running at 3,000 r.p.m., and have only fitted this equipment to sets of large shaft diameter operating at a speed of 1,500 r.p.m. where there is a tendency for the shaft to deform due to uneven heating or cooling. When shafts are comparatively small in diameter they have not deemed it necessary to fit continuous barring gear on this account whilst others claim that this is desirable where turbo-alternators may be required to be started up within, say, twenty-four hours of having been shut down. Motor barring gear is fitted to each end of large radial flow or double rotation sets, but only for convenience in erection and alignment and not for use in starting or shutting down. The light weight of the turbine parts makes the procedure of slow turning while heating or cooling quite unnecessary and sets smaller than 40 MW capacity are not fitted with barring gear.

A typical specification for a barring gear is :—

An electrically operated barring gear of approved design and construction shall be fitted to enable the turbine and alternator rotors to be revolved for cooling or inspection purposes. The gear shall include the necessary high-

and low-pressure oil systems for jacking and continuous cooling of the turbo-alternator rotor bearings, and shall be capable of running continuously for periods of at least eight hours when shutting down the set.

The value of continuous barring or rolling gear is being readily appreciated by station operating engineers with the large sets now in service. As an example, a 50 MW set was shut down nightly at 10 p.m. and put on load again at 6 a.m. the next morning for over one year. During the shut down period the set was kept turning, and at no time was vibration experienced during starting-up next morning. How soon a turbo-alternator may be run up to speed and take load at any desired time is a point of utmost importance, and the possibility of damage to the set and the objectionable vibration produced calls for consideration. When a turbine is started up in a half-warm condition, excessive vibration may take place. If a set has been shut down only for a short time and is still hot, or if it has been out of service for sufficient length of time to have become cold, then no vibration is likely to be experienced when starting up. More often than not a turbine will be in an intermediate condition and vibration may under certain circumstances occur on re-starting due to unequal cooling of the turbine rotors. The motor-driven turning gear keeps the set continuously in rotation when warming through and also when taking off load, thus obtaining even heating and cooling throughout. It is desirable in the operation of power stations that sets should be capable of being put quickly and easily in commission. The starting procedure adopted for 75 MW sets calls for careful consideration. The practice in one station is to start up these sets with a 3-in. Hg. vacuum without the aid of a gland sealing steam. which is not turned on until the set is up to full speed. This prevents the impingement of hot steam on one portion of the shaft during the time vacuum is being raised and necessitates large stand-by air ejectors. The time required depends largely upon the capacity and type of set, and the rate of picking up load is governed by the temperature of the turbine casing, the latter depending on the extent to which the set has cooled when out of service. A rate of loading of about 1,000 kW per minute has been suggested but this appears somewhat rapid after a set has been shut down for two days or so. Sets of from 15 to 40 MW may be gradually loaded to full capacity within say twelve to thirty-five minutes after being synchronised. The time taken to run up a set will, of course, depend upon the running up and putting into operation of the associated auxiliaries. Turbo-alternators of 30 MW output have been run up to speed in twenty

to thirty minutes without any special precautions being taken. Wherever possible the longest time available should be taken to load up a set especially if it has just been commissioned. Large shafts should be warmed and cooled with care to avoid bowing due to uneven heating and cooling. Any uneven cooling from a temperature of 600° to 800° F. down to standstill temperature brings stresses of considerable magnitude into play. Further, long and heavy rotors, 60 ft. long and over 100 tons in weight, have to be reckoned with. When a turbo-alternator is shut down and allowed to come to rest the lower half of the casing cools more rapidly than the upper portion, and this uneven cooling tends to bow the shaft. On starting up a set with the shaft in a distorted condition pronounced vibration will be prevalent and a much longer time will be necessary in running up to speed. A shaft in this condition may be straightened by running for a short period at a speed of between 200 to 300 r.p.m. Indicators may be provided on the shaft to bring to notice any deviation from the straight.

The manually-operated type of turning gear consists of a worm engaging with teeth on the flange of the main coupling and is operated without removing the bearing cap. When not in service the worm is removed. A lever with a crossbar fitted at the end facilitates operation by two men. Two such barring gears are provided, one working between the H.P. and I.P. turbine, and one between the L.P. turbine and alternator. With this arrangement the set can be rotated by means of the two barring gears, or by disconnecting the coupling between the L.P. turbine and alternator; the turbine rotors or the alternator rotor can be rotated independently with one of the barring gears.

Electrically-operated barring consists of a motor driving through a train of gears on to the rim of the main coupling which revolves the shaft continuously during the shut-down period. The time taken for a large turbo-alternator to cool down may vary from four to sixteen hours, or even more, depending upon the type of turbine. Another feature of importance is that of cooling the shaft journals during the closing-down period. This is essential to prevent damage to the bearing liners due to transference of heat from the turbine rotor to the journals during this period. The barring gear may be mounted on the L.P. pedestal cover between the turbine and alternator, or the exciter end of the alternator, and brought into operation by means of a hand lever, but arranged to disengage automatically when the set has approached full barring speed. In some installations the barring gear trips out automatically when a

speed of 20/30 r.p.m. is reached. The barring gear pinion is kept in engagement automatically by the power transmitted so long as the motor is turning the rotors, but as soon as the turbine revolves under its own steam at a speed high enough to overrun the motor drive, the pinion is automatically withdrawn. It is thus impossible

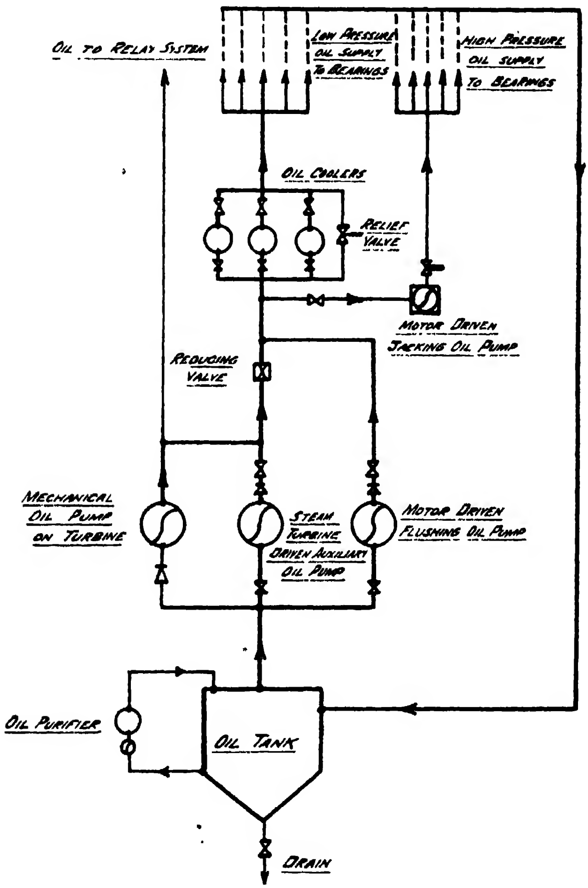


Fig. 288. Diagram of Oil Lubricating System.

for the gear to be inadvertently left in engagement when the turbine is being brought up to speed under its own steam. A locking device may be provided to hold the gear in the "off" position until reset by hand. Some makers fit underslung barring units and these appear to have advantages. The minimum speed at which the shafts may be turned is important and depends amongst other things

upon the load and viscosity of the lubricating oil. It has been stated that the critical figure below which the speed must not fall if an oil film is to be maintained is in the neighbourhood of 18 r.p.m. The speed of rotation of the shafts required to prevent temperature deflections is very small probably about 2 r.p.h. As an approximation the minimum speed of the rotor shafts may be estimated if the

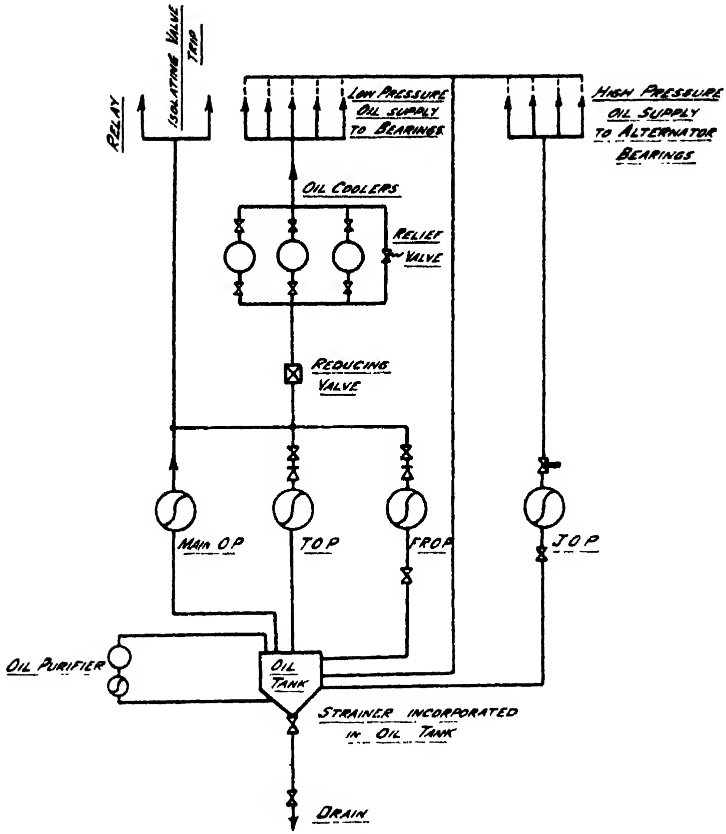


Fig. 289. Alternative Arrangements of Oil Systems.

viscosity of the oil and bearing load is known. If very low rolling speeds are adopted it may be necessary to maintain the high pressure oil supply throughout the rolling period. If the rolling gear be arranged so that the surface speed of the journals exceeds the critical journal speed for minimum friction, then the high-pressure oil can be discontinued when the gear has attained full speed. The critical journal speed is about 20 ft. per minute, and gears designed to keep

the shafts rotating at slightly above this speed are preferable to lower speed gears. Where special lubricating systems are provided. lower speeds may be adopted. In practice, speeds from 14 to 25 r.p.m. appear to be satisfactory, and in addition "inching" control is included.

On 50 MW, 1,500 r.p.m., sets a turning speed of 2 r.p.m. has proved suitable. To reduce the torque on the barring gear a separate high-pressure oil system operating at a pressure of about 1,000 to 2,000 (p.s.i.) supplies the turbine and alternator main bearings. This high pressure lifts the shaft journals off the bearings and establishes an oil film before the barring gear is put into operation and so prevents damage under slow running conditions. A separate motor-driven positive high-pressure oil pump or jacking pump is installed for this purpose. Each bearing supplied at high pressure has its own pump plunger, thus ensuring that no bearing is starved.

Another auxiliary motor-driven pump or flushing pump is provided to supply the oil for lubricating purposes during the slow turning period. This pump can also be arranged to serve as a standby to the turbine-driven auxiliary oil pump. The flushing pump also supplies the barring gear with lubricating oil. Some makers have only considered it necessary to provide for jacking the alternator rotor and a very small pump is required. Oil systems are illustrated in Figs. 288 and 289. Consideration has been given to other methods of overcoming the shut-down period difficulties. For example, it has been suggested that a cover of heat-insulating material could be placed over the casing and the intervening space heated electrically. The casing would then be maintained at normal working temperature during shut-down periods and permit of practically instantaneous starting. In power-station operation the conditions are such that generating units of 30 to 60 MW may only be required for peak load periods and may therefore have to be re-started almost daily, and in extreme emergency it may be essential that these units be put into service in the shortest possible time. To obviate difficulties from uneven cooling it is not absolutely essential to keep the shafts turning continuously, for it would suffice to turn or "inch" them through part of a revolution at intervals of, say, half an hour. The gear required for intermittent service would have to deal with very large torques and general practice appears to favour continuous turning at a slow speed.

Control of Barring Equipment. The motors are usually of the squirrel-cage type arranged for direct on line starting. The flushing

pump can have a d.c. motor and in the event of power failure take a supply from the station battery. In this way the pump will maintain oil pressure to the bearing while the set is slowing down due to loss of steam when the speed is too low for the main oil pump to be effective. The auxiliary steam pump would also serve this purpose unless complete steam failure is experienced. The sequence of starting up is as follows :-

(1) Start flushing oil pump.
(2) ,, jacking ,, ,,
(3) ,, barring drive.

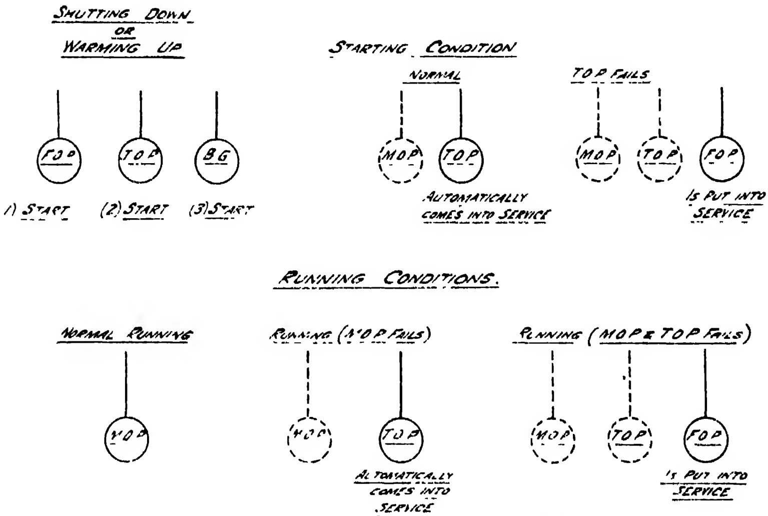


FIG. 290. Key Diagram of Oil Pumps and Barring Gear.

The reverse order being taken when shutting down.

A number of makers insist that the sequence of operations should be adhered to and to ensure this being done sequence control gear is installed. Some makers do not consider sequence starters necessary, reliance being placed on the operating staff to carry out the starting of the auxiliaries in the correct order. Fig. 290 gives key diagrams for operating conditions. When rolling speeds of 15 to 20 r.p.m. are adopted, it is possible to cut out the high pressure pump after rotation has started. With low-rolling speeds of $1\frac{1}{2}$ to 5 r.p.m. it is necessary to keep the jacking pump in service during the whole of the shut-down period. Some possible control schemes are shown in Fig. 291.

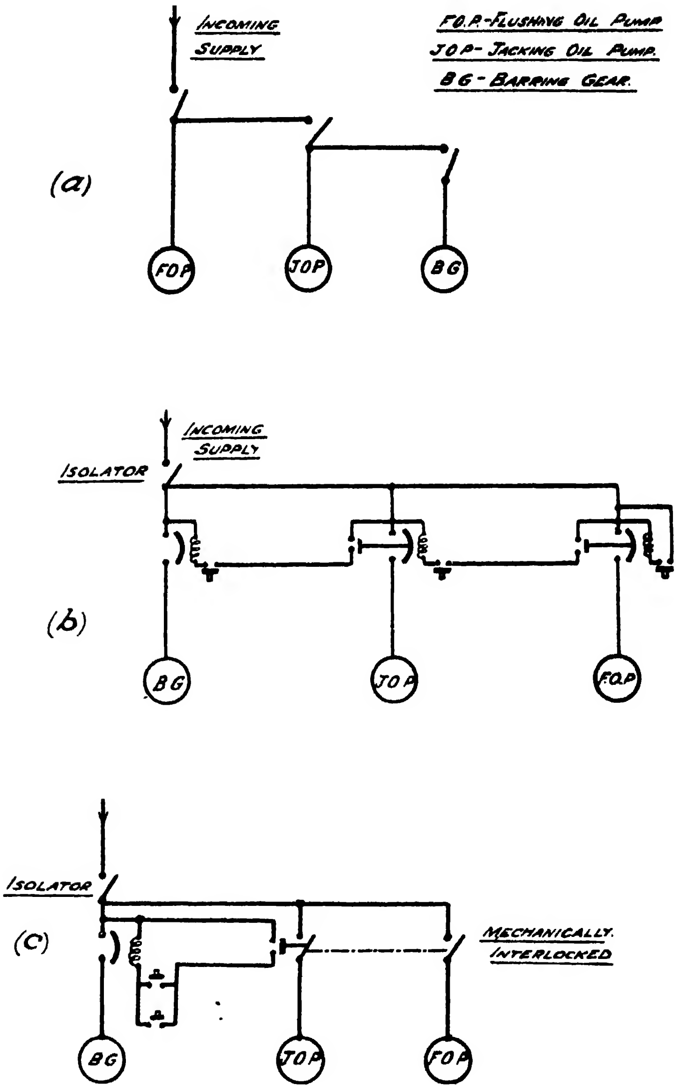


FIG. 291. Control Systems for Electrically Operated Barring Gear.

Barring gear motors are subject to the continuous vibration of the main set and their ball bearings very soon become noisy and in some cases are damaged.

Data relating to turbo-alternators fitted with barring gear are given in Table 46.

TABLE 46. *Electrically-driven Barring Gear Data*

Type of Turbine	M.C.R. Rating MW	Speed r.p.m.	High Pressure Oil lb. per square inch	Turning Speed r.p.m.	Motor B.H.P.	Remarks
Impulse reaction 3 cylinder.	30	3,000	1,000 Alternator only.	20	12	Direct on line starting. Starting torque equiv. to 48 H.P.
Impulse reaction 2 cylinder.	30	3,000	1,200/1,500	25	20	Rotor starter.
Impulse reaction 2 cylinder.	30	3,000	1,000	20	12	Rotor starter.
Reaction 2 cylinder.	30	3,000	2,000	14/20	8	Direct on line starting. Starting torque equiv. to 25 H.P.
Impulse 2 cylinder.	50	1,500	1,500	$1\frac{1}{2}/2$	10	Direct on line starting.
Impulse 3 cylinder.	75	1,500	800/1,000	8	25	Rotor starter.
Radial flow.	40/50	1,500	Nil.	20	2/6	Motor at each end. Direct on line.

Thrust Block. To locate the wheels correctly in an axial direction relative to the cylinder, a thrust block is provided in the high-pressure bearing of the high-pressure cylinder and in the common bearing housing between the two cylinders. Each thrust block can be rotated by worm gear controlled from the outside of the bearing pedestals so that the clearances can be adjusted while the turbine is running. Unauthorised interference is prevented by locking the clearance adjusting gear. The thrust block may be either of the multi-collar type, in which a number of collars lined with white metal engage with collars machined on the turbine shaft, or of the well-known "Michell" type in which the thrust surfaces of the thrust block are fitted with segmental tilting pads lined with white metal and engage with a single thrust collar on the shaft.

The amount of thrust in a turbine depends upon the design of blading used. To prevent the turbine shaft "floating" axially the amount of the thrust oil clearance, it is necessary to proportion the areas of dummy pistons and blading so that the thrust collar is always located against one side of the thrust bearing. The turbines

may be designed with the resultant steam thrust directed towards either the exhaust end or the steam end.

Only a small effort is required to cause a rotor to float when it is running excited on no-load, although when the coupling is transmitting power the movement is less free. One cause of rotor thrust is the binding of the coupling between the alternator rotor and the turbine which prevents free expansion of the rotor due to temperature. Examination of the driving faces of the coupling claws will reveal pitting if binding has taken place when the set is on load. The driving faces can be resurfaced for further service. Another feature which may result in increased expansion of the alternator rotor shaft is running the set on high prolonged loads thus reducing the clearance at the exciter end of the thrust. If the rotor is not free to move in the coupling this will result in an excessive pressure on the exciter end thrust ring eventually causing its failure.

Steam Rotor Position Indicators. The axial position of the high pressure rotor relative to the casing, giving the correct clearance between the rotating blades and the diaphragms, or stationary blades, is fixed by the thrust block. It is desirable to check from time to time the position of the rotor while the set is running. Multi-cylinder turbines in which the rotor shafts are not solidly coupled together are provided with a position indicator for the high-pressure rotor and also an indicator for the low-pressure rotor. In designs where the rotor shafts are solidly coupled together only one position indicator is provided.

Expansion Measurement. Means for measuring differential expansion between rotors and casings of the high pressure and intermediate pressure cylinders and eccentricity of rotors are often employed on large machines and are discussed later.

Gland Packings. The annular spaces between the shaft and the casing where the shaft passes through the casing are sealed by packings at the high-pressure and low-pressure ends of the set. The glands are of two types, namely, internal and external. In impulse turbines the function of the former is to reduce the steam leakage from each cell to the cell adjacent to the low-pressure side. These glands are of the labyrinth type in which the steam is successively throttled in passing through restricted spaces between the fine edges of the metal packing strips and the surface of the spindle. The external glands are either to prevent the leakage of steam which is at a higher pressure than the atmosphere, or to prevent the in-leakage of air when the pressure of the steam in the turbine casing is lower than atmosphere. The gland at the low-pressure

or exhaust end of the turbine has to seal the casing against the in-leakage of air.

There are three chief types of external glands: (1) labyrinth, (2) carbon ring, and (3) hydraulic glands or water seals. All except the latter type of gland require either a high- or low-pressure steam supply. A portion of the steam supplied leaks into the turbine whilst the remainder leaks outwards into the turbine-house and prevents the inward flow of air.

The gland packings, sealed by steam, are provided with pipes and control valves for admitting or exhausting steam as required. Where the rotational speed of the shaft is not unduly high the use of carbon packings is often adopted. These consist of segmental carbon rings bearing against a liner on the shaft and held in position in a removable grooved casing by bands and springs.

To prevent the sealing steam escaping into the turbine house each gland is provided with a small coil condenser through which a portion of the main condensate is passed to serve as cooling water. This water is tapped from the discharge side of the extraction pumps and is returned to the main condenser after use. The water formed by the condensation of the sealing steam drops into open tundishes and so permits the operation of the gland to be noted by the attendant. By temporarily shutting off the cooling water the amount of sealing steam is rendered visible and any adjustment can be made to the supply. In some cases each vent pipe is fitted with a flap valve which is normally closed but so adjusted that the valve will lift at a pressure above atmosphere. A regulator may be provided for automatic control of sealing steam. Fig. 292 shows one type the control of which is as follows: a high-pressure steam supply is led to all glands and enters as indicated. By controlling the valves leading to each gland the correct steam pressure at these points can be obtained to prevent air being drawn into the turbine when vacuum exists behind the gland. The valve to the exhaust-end gland of the low-pressure turbine—or valves to the two glands adjacent to the two exhausts of a double-flow low-pressure turbine—is kept open owing to the presence of a vacuum at all loads, but the valves to all other glands are opened only when load conditions are such that there is a vacuum at these points.

The steam supply for gland sealing is usually taken from the range before the stop valve or the combined stop emergency valve. Desuperheaters are sometimes used and in some cases use is made of steam bled from a suitable stage of the H.P. turbine after the set has run up. Where steam is bled from the turbine great care is

necessary to ensure that the live steam valve is closed when taking the set off load otherwise it may run to overspeed and continue to rise to a dangerous speed although the main valves are closed.

Valve and Governor Gear. In general, the governing system of a steam plant is much more responsive to load changes than is that of hydro plant, so that as the load rises the tendency is for most of the increase to be picked up. For this reason, a limiting device can be fitted to the governing system to ensure that the load carried by the steam plant does not exceed a predetermined amount. With the increase in size of interconnected electric power systems and the

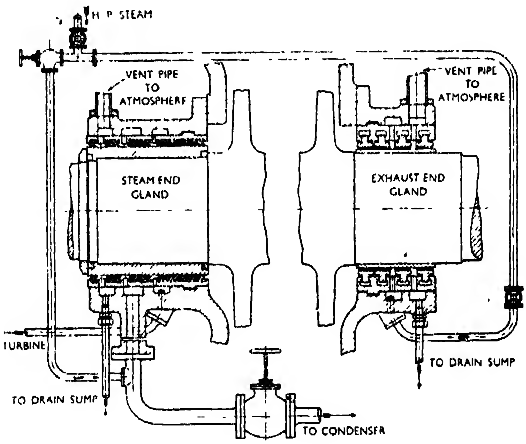


FIG 202. Sectional Arrangement of Shaft Glands—Labyrinth type. (English Electric Co. Ltd.)

resulting problems in frequency control and stability, the governing of turbines driving synchronous alternators is worthy of special consideration. The present-day methods are :—

(*a*) Speed or pendulum governing, where the control is from the machine speed.
(*b*) Watt governor, where the control is from the alternator output.

The first method has the disadvantage that after load changes the speed is no longer 50 cycles per second, and even if this is corrected by supplementary frequency control a time error exists which must be removed to make electrical time identical with standard time. A possible alternative is integral control or time error governing and details are given in *The Electrical Engineer and Merchandiser*

(Aus.), Feb. 16th, 1953. An isolating stop valve is included in the steam main to the turbine and is usually placed on the steam receiver, arranged for motor operation with remote control from the turbine house operating floor and also with emergency hand operation at the valve. In some cases a manually-operated isolating stop valve has been fitted on the receiver and also on the steam chest. The by-pass valve on the steam chest stop valve can be of normal size for by-pass service or may be large enough to pass a desired quantity of steam for starting-up purposes. At the steam inlet to the turbine a combined stop and emergency valve is fitted and arranged for operation from floor level; it may be tripped at any time by the turbine driver. The steam supply to the turbine passes through this valve which is sometimes termed a runaway valve. This valve is of the "double-beat" pattern, with two steam-entry ports, so that the valve is balanced at all times and therefore requires a comparatively small force to operate it. Two strainers are fitted in the valve casing, one in each entry port, to prevent the ingress of foreign material to the turbines. Fig. 293 shows one arrangement of governor and oil pump drives.

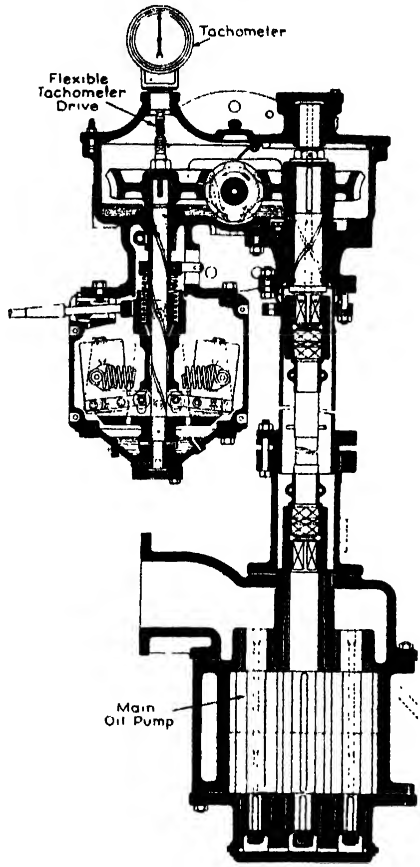


FIG. 293. Sectional Elevation of Main Governor and Main Oil Pump. (B.T.-H. Co.)

The runaway stop valve consists of a steam valve coupled rigidly to a controlling piston which is spring loaded on its upper side. Oil pressure is supplied to the lower side of the piston from the high-pressure (relay) oil system and this normally forces the piston upwards against a controlled stop which can be moved up or down

by rotating the hand wheel. The valve, when open, can be closed either completely or to any desired extent by turning the hand-wheel in the opposite direction. After the valve has closed automatically it is impossible for the turbine to be re-started except by the turbine driver. Before he can re-admit steam he must first turn the hand-wheel until the sleeve has been screwed down into contact with the piston, and then, provided that the oil pressure has been restored, he can re-open the valve in the manner described above. It should be noted that the turbine can neither be started nor re-started until the proper oil pressure in the system has been provided by the auxiliary oil pump which is driven by steam turbine or electric motor. If desired, a solenoid may be mounted on the turbine and connected to a switch in the control room, and so arranged that when the solenoid is energised the oil pressure in the emergency stop valve is released and the valve closes. Since this valve is oil operated it provides complete protection against the risk of the turbine being started before the auxiliary oil pump is working. The function of this valve is to provide a means of shutting off steam from the turbine quickly and completely, either by hand or automatically if the turbine overspeeds. Should an interruption of the oil supply occur, such as is occasioned by the tripping of the emergency trip valve, the failure of an oil pump or a broken high-pressure oil pipe, the valve will close automatically.

There are two principal methods of governing turbines: (1) throttle control; (2) nozzle control. In the first method the steam supply to the turbine is regulated by a throttle valve. This method is used on all reaction turbines because steam must be admitted at the whole periphery of the first row of blades. It is not so efficient on light loads because the steam is throttled and the full heat drop is not being used, or on overloads because high-pressure steam is by-passed to the fifth or more expansion, causing large losses and also subjecting these parts to high pressure and temperature. Nozzle control as used on combined impulse turbines consists of dividing the admission nozzles into groups and having each group controlled by a valve, these valves being opened consecutively according to the load on the turbine (Fig. 294).

Only the first row of blades is subjected to high pressure and temperature and the steam is throttled in three, seven or ten stages, depending on the number of nozzle valves.

There is no throttling of the steam except at that valve which is the last to be opened. The loss of available energy due to throttling

is therefore much less than with the first method. Where throttle control is used the moisture content will always be at a maximum

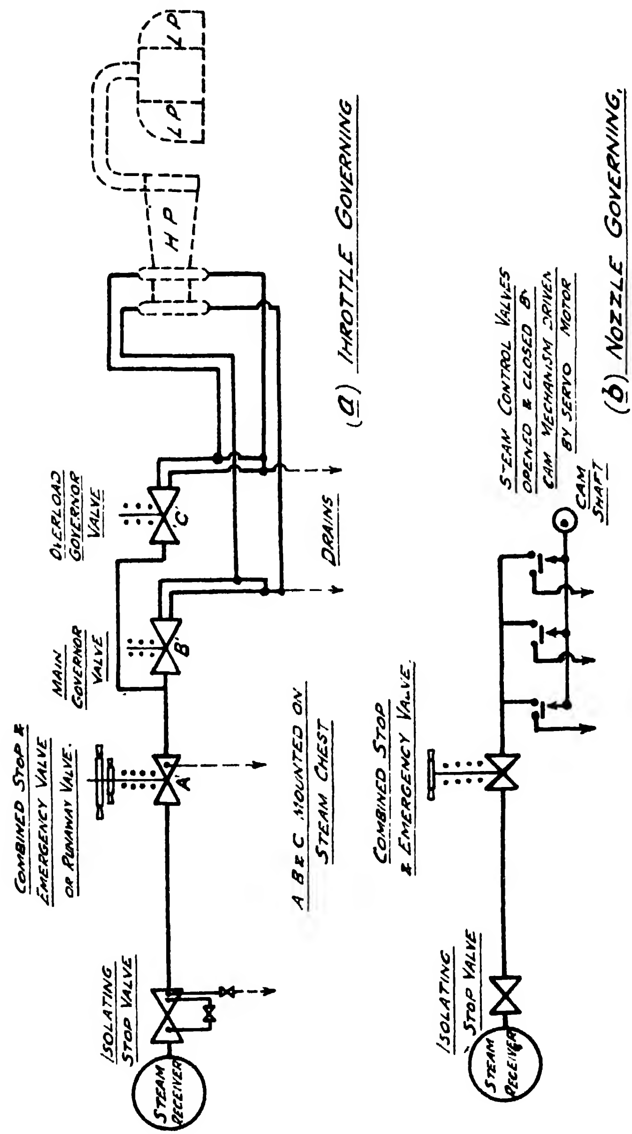


FIG. 294. Turbine Control Valves.

value at the economical load, the steam being drier at partial loads and overloads. This control is more usually adopted for sets which operate principally at their designed economic load. With nozzle

control the moisture at the partial loads will vary between a constant value and a slight increase, whilst at overloads the amount of water will be higher than at economical load. Nozzle control is used for sets operating over wide variations of load and gives a flatter steam consumption curve, though this advantage is not so perceptible in the case of multi-cylinder sets, and there is little to choose between the two systems from the point of view of overall efficiency. 30 MW turbines usually have nozzle or by-pass governing gear with the economic point at 80 per cent. m.c.r. Larger full-admission turbines can have their economic points at m.c.r. This permits of shorter and more symmetrical high-pressure cylinders, less complicated control valves and governor gear and ensures very small changes of temperature in the high-pressure and intermediate pressure cylinders over a wide range of load.

The governor takes control at 5 per cent. below normal full speed and after this has been reached the emergency stop valve can be opened fully. The speed of a turbine is ordinarily fixed by the frequency of the electrical system and this frequency necessarily varies when changes of load occur, but with a large electrical system the change in frequency caused by a total load change of say the full output of one set is very small. Full load tripping tests have been carried out on the national grid system. One set of tests included the simultaneous tripping of three 53·5 MW machines in order to determine the drop in the system frequency. Recording apparatus was installed for this purpose. A sent-out load of 150 MW from these machines was tripped out sucessfully on three occasions and the maximum drop in frequency observed was 0·05 cycle per second. Although the overspeed governors operated on all three machines on each occasion, they were again connected to the system and were available for full load within 24, 11 and 12 minutes respectively, for the three tests. Actually the governor functions as a load regulator. The object of the governor gear is to regulate automatically the rate of steam admission to the power demand so as to maintain the speed constant, as nearly as possible, at all loads. To enable a set to run in parallel with other sets provision has to be made to permit of making two adjustments :—

(1) To vary the speed within reasonable limits under constant load.
(2) To vary the load at constant speed.

The drop in speed between no-load and full load expressed as a percentage of the no-load speed is termed the percentage regulation of the turbine governor. In order that the speed governor be stable

it should have a positive static drop or regulation, *i.e.*, with increase in load there must be a corresponding drop in speed (Fig. 295).

If there are a number of sets operating in parallel, load variations are taken primarily by the set with the smallest percentage regulation. The following examples indicate the points in question :—

A 20 MW turbo-alternator (50 cycle) has a governor regulation of 4 per cent. What is the new frequency if a load of 10 MW is suddenly thrown off ?

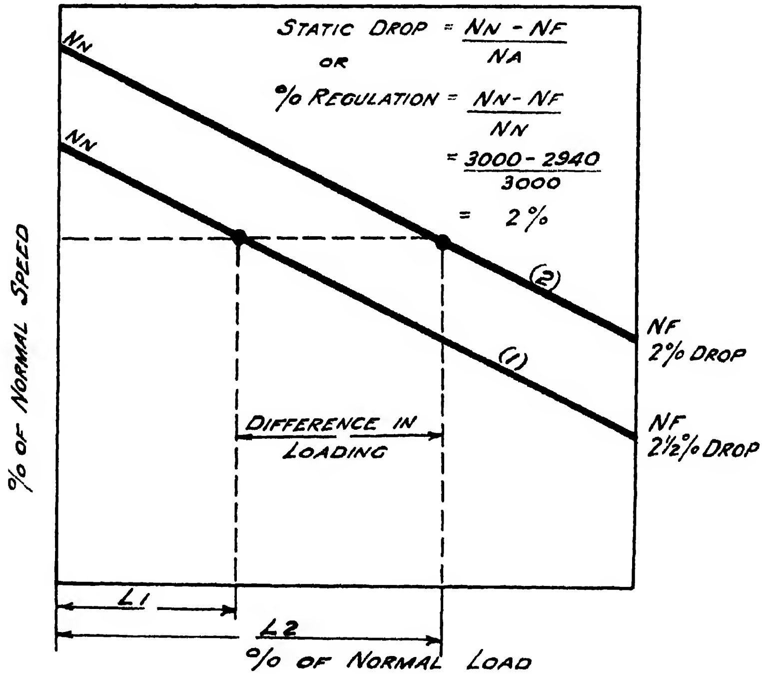


FIG. 295. Governor Characteristics.

N_N—No-load speed.
N_F· Full-load speed.
N_A—Average speed.

A drop of 10 MW would mean a speed increase of

$$\frac{10}{20} \times \frac{4}{100} = 2 \text{ per cent.}$$

$$\frac{2}{100} \times 50 = 1 \text{ cycle.}$$

The new frequency would be 51 cycles per second or 49 cycles per second if an increase in load of 10 MW.

In a power station there are two turbo-alternators, one having an output of 30 MW (2 per cent. speed drop) and the other 50 MW ($2\frac{1}{2}$ per cent. speed drop). How will they share a load increase of 10 MW ?

If the sets have similar speed-load or governor characteristics they will share any load increases in proportion to their full load rating.

In the present example the characteristics differ and it is assumed that the speed drops in proportion to the load (a straight line governor characteristic is assumed). The conditions for parallel operation are that the sets should run at the same speed and it is necessary to ascertain at what load on each set the speeds will be equal :—

Let A and B respectively be the proportions of the additional load taken by stations or sets A and B.

Set A (50 MW)—2·5 per cent. speed-drop R_A.
,, B (30 MW)—2·0 ,, ,, ,, R_B.

The sets will share the additional load in inverse proportion to their governor regulations, then :—

$$\frac{A}{B} = \frac{MW_A}{MW_B} \cdot \frac{R_B}{R_A}$$

$$= \frac{50}{30} \cdot \frac{2 \cdot 0}{2 \cdot 5}$$

$$A = 1 \cdot 33B$$

Now $$A + B = 10 \text{ MW}.$$

$$1 \cdot 33B + B = 10 \quad \therefore \ B = \frac{10}{1 \cdot 33}$$

$$= 4 \cdot 3 \text{ MW}.$$

$$A = 5 \cdot 7 \text{ MW}.$$

Had the sets been of the same capacity then their respective additional loads would have been :—

$$\frac{A}{B} = \frac{2 \cdot 0}{2 \cdot 5} \quad \text{or } A = 0 \cdot 8\,B$$

$$A + B = 10 \text{ MW}$$

$$0 \cdot 8\,B + B = 10 \quad \therefore \ B = \frac{10}{1 \cdot 8}$$

$$= 5 \cdot 55 \text{ MW}$$

$$A = 4 \cdot 45 \text{ MW}$$

or alternatively :

$$10 \times \frac{2}{2 + 2 \cdot 5} = 4 \cdot 45 \text{ MW (50-MW set)}$$

$$10 \times \frac{2\cdot5}{4\cdot5} = 5\cdot55 \text{ MW (30-MW set)}$$

Set A—2·5 per cent. drop—normal speed 1,500 r.p.m.
Full load speed = 1,462·5 r.p.m.
Set B—2·0 per cent. drop—normal speed 3,000 r.p.m.
Full load speed = 2,940 r.p.m.

Had both speed drops been the same the division of load would have been as follows :—

$$10 \times \frac{30}{80} = 3\cdot75 \text{ MW (30-MW set)}$$

$$10 \times \frac{50}{80} = 6\cdot25 \text{ MW (50-MW set)}$$

The load on any turbo-alternator depends on the amount of steam admitted to the turbine driving it. If two or more alternators are running in parallel the division of loads is carried out by adjustment of the turbine governors to obtain most economical operating conditions. It is inconvenient to determine the percentage regulation of a turbine alternator governor unless the alternator can be connected to an independent electrical system and gradually loaded to full capacity, noting the drop in speed from no-load. A test pond would appear to be the only alternative.

The speed of a turbine is regulated by a centrifugal governor which acts through a relay and not directly on the main throttle valve. In the case of nozzle control the governor does not actuate the steam control valves directly, its sole function is to move the sleeve of a pilot valve and thus enable the latter to supply oil under pressure of about 60 p.s.i. to a servo-motor which, by means of a cam shaft, mechanically opens and closes the control valves to suit load conditions. As the sleeve of the pilot valve is very light, the governor quickly responds to changes in speed. The relay consists of a pilot valve which is moved through levers or sleeves by the main governor, thus controlling the supply of oil under pressure to a cylinder and piston by means of which the throttle valve is operated. The object of introducing the relay is to reduce the amount of work the governor has to do and so increase its sensitiveness.

The function of the governor is to vary the pressure of the pilot (Fig. 296) oil supply as the speed of the turbine varies. The governor system is operated by a supply of oil the pressure of which is controlled by the speed of the turbine, and this in turn controls the pressure of another and larger supply of oil, which varies the lift of the

valves admitting steam to the turbine. Both supplies of oil are tapped off the high-pressure oil supply (50 to 70 p.s.i.) (Fig. 297). The first supply, the pressure of which is controlled by the turbine speed, is called the pilot oil supply and the other the power oil supply. The

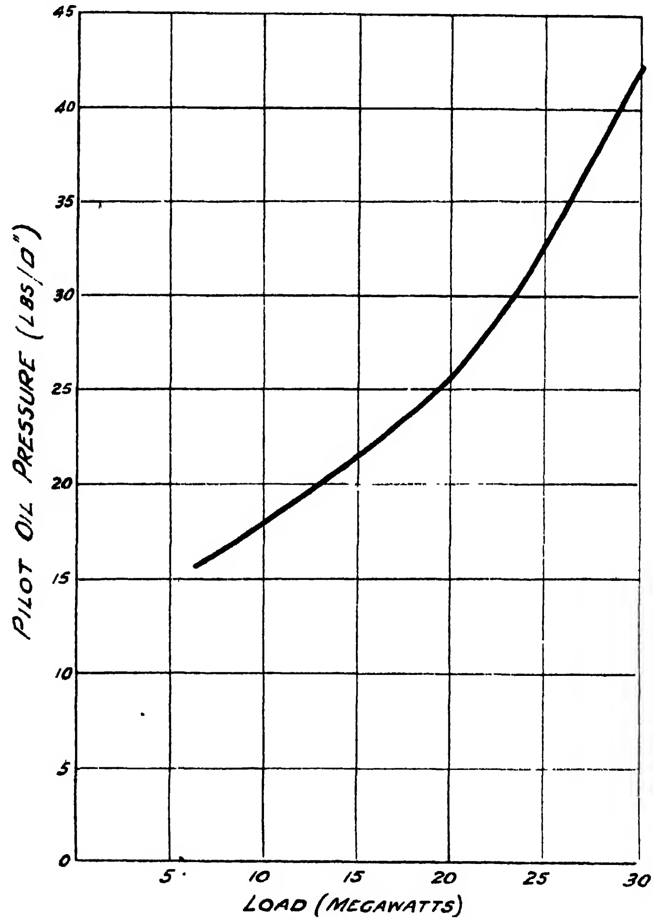


FIG. 296. Pilot Oil Pressure Characteristic.

pilot oil is led through a locked relay regulating valve, the feed then divides, one to the governor and the other to the oil relay gear. An emergency trip valve is included through which all this high-pressure oil has to pass. The purpose of this valve is to close the runaway stop valve and the governor valve, should the turbine run to overspeed. Loss of vacuum and failure of lubricating oil

supply are also guarded against. This trip valve may also be operated by hand at any speed if it is desired to shut down the turbine in an emergency. To test the hand tripping gear it is advisable to

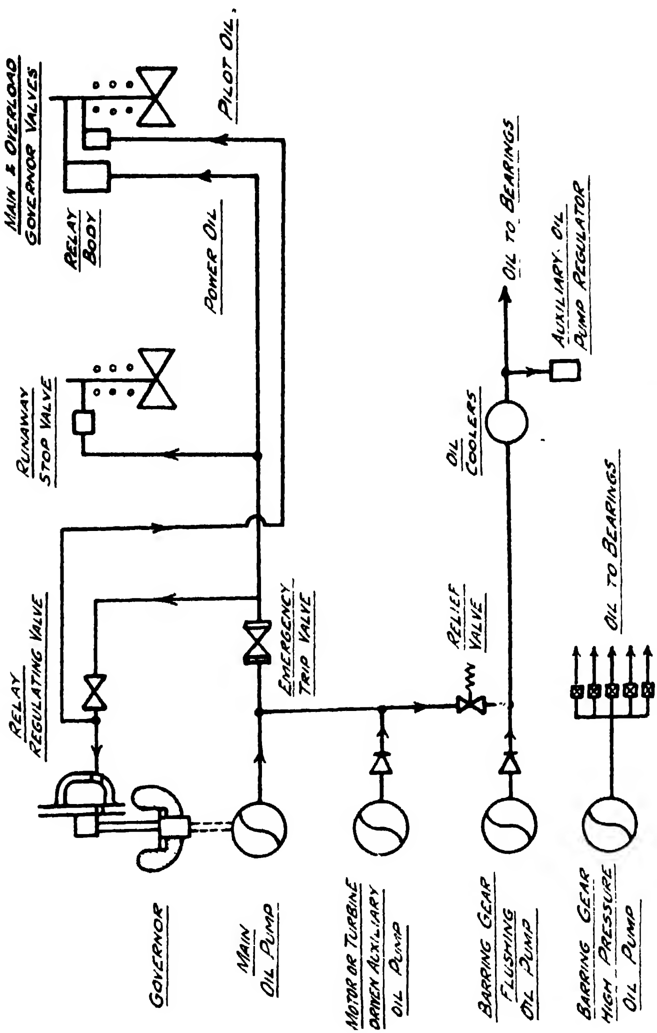


FIG. 297. Diagram of Oil System. The main and overload governor valves are exactly similar and operate from the same oil supplies. The pilot spring compression rates and initial compressions are different and so adjusted that the valves are opened at different and appropriate loads.

use it whenever the turbine is shut down; the turbine should also be run to overspeed at regular intervals, say, once a month, to test the emergency governor. All the governor parts should be kept free from dirt, sludge, etc., to prevent or minimise the effect of sticking

or seizure of parts which should be free to move, especially valves and release devices. Such happenings may result from dirt or sludge in the governor oil system, carbonised oil on valve spindles and abnormal expansion or otherwise. To facilitate rapid closing of main emergency steam valve should the turbine overspeed it has been suggested that one of two methods are practicable, namely :—

(1) Emergency steam valve to be fitted with both auto-mechanical and auto-electrical quick operating closing devices.

(2) To provide two emergency steam valves in parallel, both being fitted with quick operating closing devices. The two valves to be so arranged that either can be tested and re-set independently of each other without shutting the turbine down.

The governor throttle valves, usually two in number for a reaction turbine, have a pair of seats in parallel. One valve controls the amount of steam entering the turbine from no load until the normal economical load is reached, after which the second valve opens automatically and controls the admission of the steam to the by-pass.

Governor specifications vary according to requirements and as a guide an example is given for a 70 MW, 1,500 r.p.m., set.

" Governors of the mechanical type operating an oil relay shall be provided and be so arranged that the speed at any load up to maximum load can be varied gradually from 5 per cent. above to 5 per cent. below normal speed while the turbine is running, and without affecting the sensitiveness of the governor. Means shall be provided for adjusting the speed by hand at the turbine as well as by remote electric control from the control room. The governor control gear shall be provided with overwinding cut-out switches. The main governors and the emergency governor shall operate without causing the turbine to race or hunt under any conditions or variation of load from no load to maximum load.

" The governors shall be normally arranged so that the steady speed shall not vary more than 2½ per cent. when throwing on or off the economical load and 4 per cent. when throwing on or off the continuous maximum load, and the time within which a steady speed is attained in each shall not exceed ten seconds.

" A mechanical emergency governor shall be provided and arranged to cut off steam when the speed rises to 1,650 r.p.m. by closing both the governor valve and the emergency valve.

" The emergency governor shall preferably be of the shaft type, but in any case shall be driven entirely independently of the main governor.

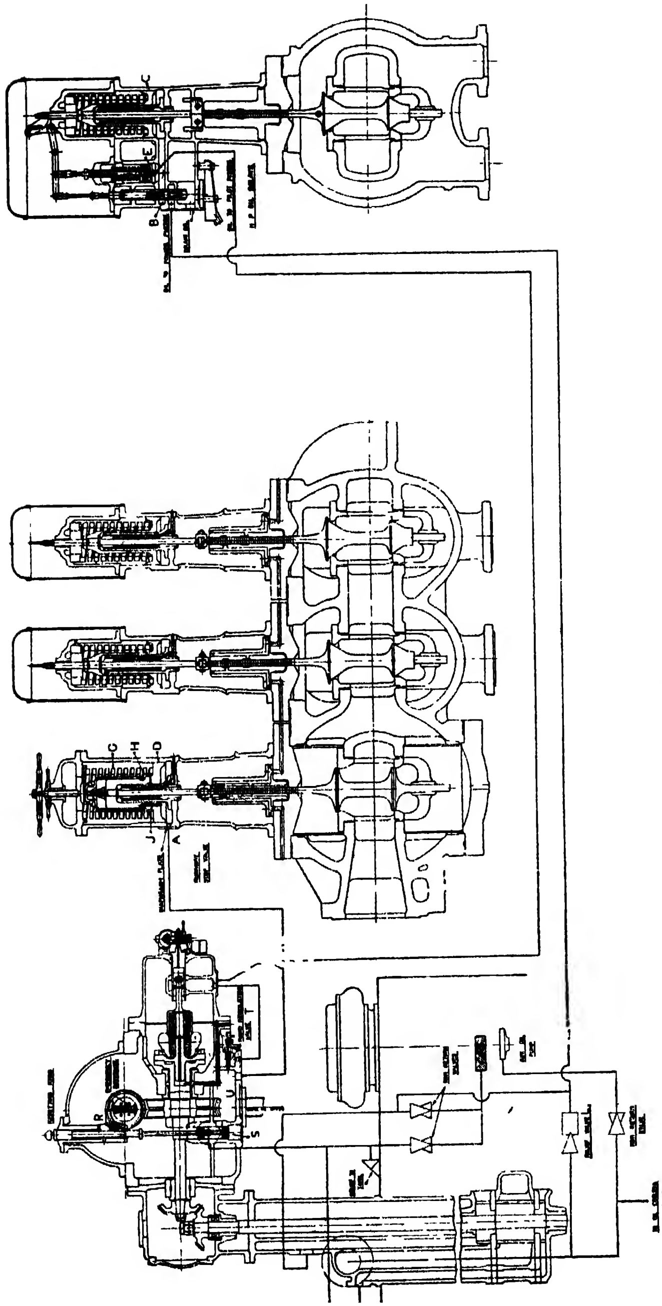


FIG. 298. Section through Steam Chest and Diagrammatic Arrangement of Governor and Valve Gear. (C. A. Parsons.)

"The governor valve and emergency valve shall be arranged for hand tripping near the turbine."

There are numerous designs of governors and Fig. 298 shows one arrangement.

The main governor is of the centrifugal type driven by means of a worm and wheel from an extension of the main turbine shaft, the motion of the governor sleeve being transmitted by either links or levers to a small pilot valve which controls the supply of oil under pressure to the various control valves operated by oil pressure. Trouble has been experienced due to wear of worm wheels which has been attributed to shaft currents. A ring fitted to the shaft

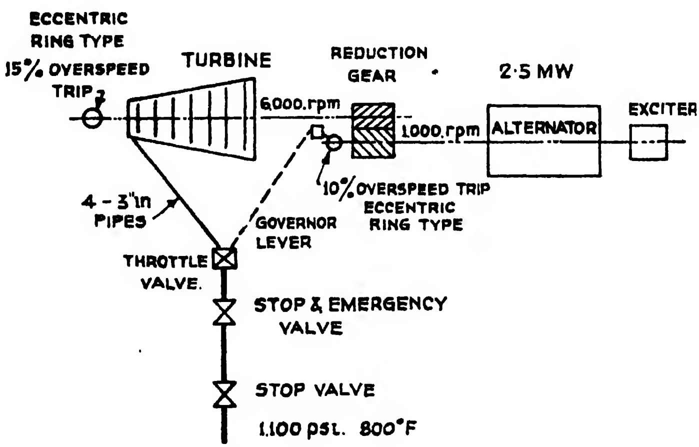


FIG. 299. Turbine Tripping Devices.

with an earthed brush connection appears to be the most satisfactory method of overcoming this. A brush in direct connection with the shaft causes wear and reduces safety factor.

The emergency governor which automatically shuts off the steam supply to the turbine in the event of the speed exceeding a predetermined figure, about 10 per cent. (B.S.S. 10 per cent. + or − 1 per cent.) above normal running speed, is mounted directly on the turbine shaft. It consists of an unbalanced ring held concentrically with the shaft by means of a spring so long as the speed of the shaft remains normal. An increase of speed above the normal causes the centrifugal action of the ring to overcome the spring and to allow the ring to fly out eccentrically, releasing a trip lever and spring which immediately closes the emergency valve, thereby shutting off the steam supply. At the same time the oil pressure

to the relay cylinders is reversed and the throttle valves are closed by the action of the power piston springs and the oil pressure. Fig. 299 shows the arrangement of tripping devices for a small high-pressure topping plant (see also Fig. 8).

In some designs a device is provided to facilitate operation of the emergency governor at a reduced speed and prevent undue overstressing of rotating parts each time the set is run to overspeed.

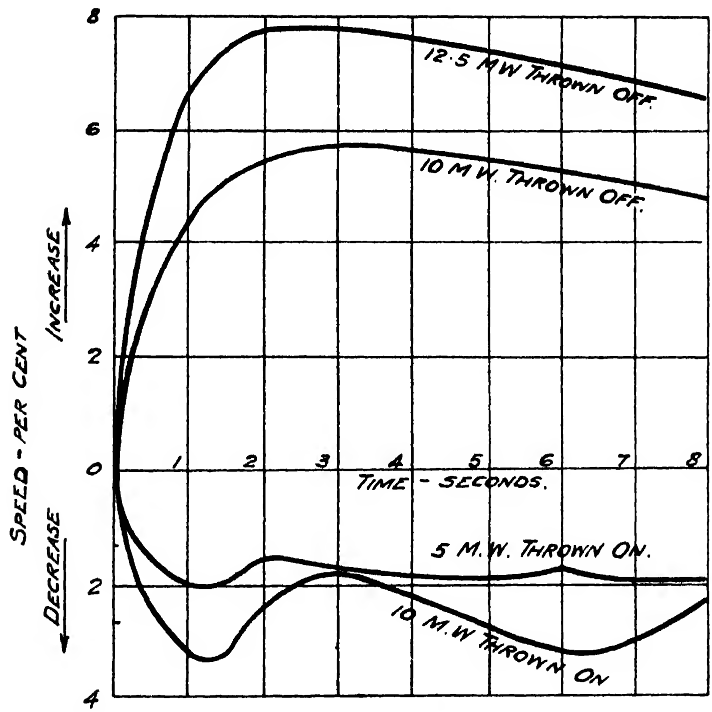


FIG. 300. Governor Characteristics.

The shedding of large electrical loads may cause serious disturbances on the system and the turbine governors should be capable of holding the speed and so prevent tripping of the emergency governors (Fig. 300). If the sets are shut down due to governor tripping it will take longer to restore supply as tho sets have 'to be run up and synchronised. Such conditions are more likely to arise at light-load periods unless an alternator is suddenly isolated on to a feeder section of reduced load. Some engineers have increased the emergency setting to 12½ per cent. in an endeavour to prevent dislocation of supply due to sudden loss of load. It is rather unfortunate that

load throwing-off tests are not more frequently employed in view of the importance of the equipment involved and the fact that specifications provide for a given performance.

During load throwing-off tests the governor is only called upon to close the governor valve whereas under electrical system fault conditions it is possible for the governor to be called upon to first open the governor valves to deal with the increased load due to the fault and then close them almost instantaneously when the fault is cleared by the opening of the circuit breaker concerned. This would probably bring about an increased time in closing the governor valves with consequential higher rise in speed. The boiler drum pressure will rise to blowing off pressure and as less steam will flow to the turbines the frictional drop in the pipe lines will be reduced and both will tend to affect the operation of the governor.

Pressure-operated load pay-off and trip gear for governors of large sets, especially when arranged on the unit system, has received attention ; relays partly close the governing valves on fall of steam pressure to a predetermined limit and reopen them for faults of short duration, but trip the emergency valve for a heavy drop in steam pressure. General practice now is to use a vacuum-operated bellows relay, which closes the governor valves temporarily if the vacuum falls to 25 in. and trips the emergency valves if the vacuum falls further to 15 in.

To facilitate control of turbo-alternators from the control room a small reversible motor, about $\frac{1}{12}$ to $\frac{1}{8}$ B.H.P., is connected through gearing to the governor-control gear. The operation of the motor in either direction is controlled by a two-way switch mounted on the governor control desk, limit switches being fitted to the governor gear, so arranged that the motor circuit is opened and reversed at the end of the travel in either direction. The motor is then only operative in the reverse direction, and in doing so will re-establish the broken circuit. The cable connections to the reversing switch or motor should be flexible enough to allow for cylinder expansion and also withstand temperature and oil.

Anticipatory Overspeed Limiting Gear. With large turbines operating at high pressures and temperatures, it is in some cases desirable to employ steam chests formed independently of the turbine cylinder. With such an arrangement the momentary speed rise on a sudden heavy or complete loss of load may, in the absence of some additional speed limiting arrangement, be sufficient to cause operation of the overspeed trip. This excessive momentary rise, above that inherent in all normal governor systems, is caused

by the expansion to condenser pressure of the steam in the turbine and interconnecting pipework, after the closure of the governor valves. Whereas the normal governor mechanism is operated by speed rise, the anticipatory overspeed limiting gear is operated by sudden heavy loss of load, but is unaffected by normal load changes. With short duration faults, after limiting the temporary speed rise, it also permits the normal governor system to resume control automatically after the fault is cleared. Following faults of longer duration, say five seconds or more, the sudden restoration of load involves the danger of boiler priming ; a secondary purpose of the gear is to prevent this by ensuring the gradual re-admission of steam.

The gear interrupts the steam supply to the turbine in these emergency conditions more rapidly than is possible by a normal governor system. This is effected by the rapid closure by solenoid action of the high-pressure emergency valves and where reheating is employed, also the interceptor valves between the reheater and the intermediate or low-pressure cylinder. By such means the momentary speed rise resulting from loss of load is kept below the limit at which the overspeed trip would operate. The automatic restoration of normal governor control after short duration faults and the retarding of re-admission of steam after faults of longer duration are effected through the medium of pressure, wattmeter and timing relays.

INSTRUMENTS

The continual trend towards the adoption of larger turbo-alternators has directed attention to the provision of a greater degree of instrumentation, designed primarily to enable operatives to detect incipient trouble and so prevent the outage of plant for a lengthy period. Turbine instrumentation in the past has been chiefly confined to the essential gauges for measuring flows of steam, etc., and recording a limited number of temperature and pressure indications. The trend now is in the provision of instruments concerned with the mechanical and thermal aspects of turbo-alternator operation.

It has been suggested that for correct co-ordination of any instrument scheme the following points are worthy of consideration :

(1) Grouping of indicating, recording or receiving instruments into one or more centralised positions.

(2) Provision of a panel for mounting the instruments which has a logical, pleasing and symmetrical arrangement.

(3) Fitting of a specially designed, soft and yet adequate illumination of the panel.

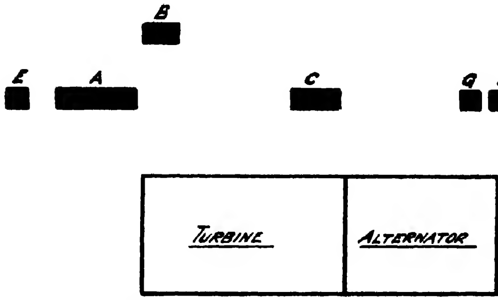


FIG. 301. Layout of Turbo-Alternator Instrument Panels and Equipment.

A—Turbine gauge panel.
B—Turbine metering panel.
C—Ejector gauge panel.
D—Field suppression panel.
E—Telegraph and telephone pedestal.
G—Air temperature alarm panel.

(4) The reconciliation of technical soundness with psychological and æsthetic requirements.

(5) Complete accessibility of all instruments for inspection and maintenance purposes.

(6) Erection of the instruments and panel, including running of cables, conduits and piping.

(7) Exclusion of dust and the alleviation of excessive vibration.

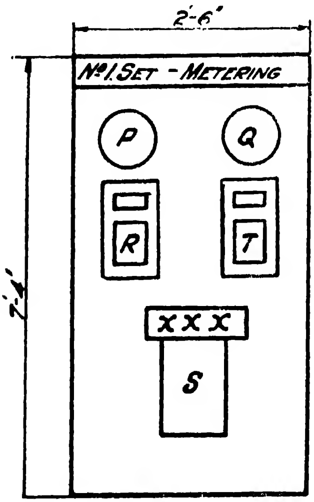


FIG. 302. Metering Panel.

P—Steam flow integrator.
Q—Raw water flow integrator.
R—Dissolved oxygen recorder. (Alternative point of measurement is after condenser.)
S—5-point efficiency recorder :
(1) Turbine steam flow.
(2) Turbine steam pressure.
(3) Turbine steam temperature.
(4) Condenser vacuum.
(5) Final feed water temperature.
T—Dionic recorder.

The instruments required vary in detail for each installation, but a number are what may be termed essential instruments and should always be included.

The turbine gauge panel is placed near the steam end of the set (Fig. 301). In some stations all recording instruments associated with the turbine and condenser have been mounted on a separate panel usually termed a metering panel (Fig. 302). This may be placed in the feed pump bay or all metering panels could be grouped in a small room with the boiler recording instruments.

Typical turbine panels are illustrated and the points of measurement are indicated in Figs. 303-308.

The instruments required are as follows :—

Steam, feed water (condensate),

raw water (make-up), cooling water, oil and vacuum, the latter being associated with the condenser. The alternator-winding indicator and air-temperature equipment will also be included.

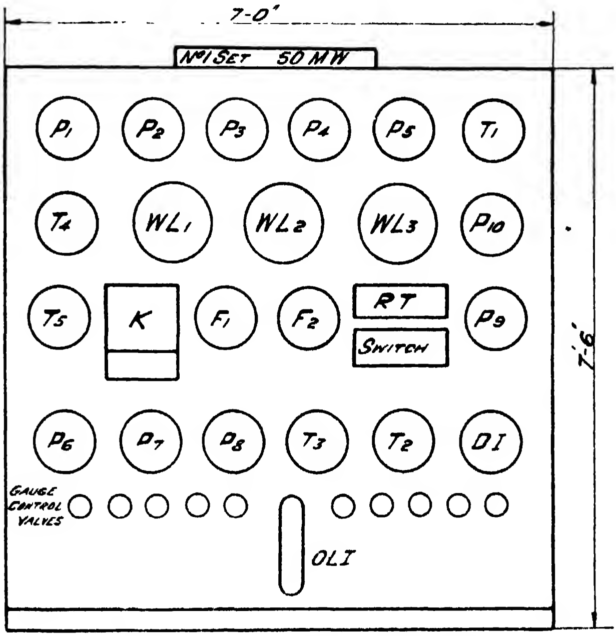


FIG. 303. Typical Turbine Gauge Panel.

Pressure Gauges

P_1—Steam before stop valve.
P_2—Steam after stop valve.
P_3—Steam at overload belt.
P_4—Steam at L.P. cylinder inlet.
P_5—Condenser vacuum.
P_6—Bled steam at No. 3 H.P. heater.
P_7—Bled steam at No. 1 L.P. heater.
P_8—Bled steam at No. 2 L.P. heater.
P_9—Relay oil.
P_{10}—Oil to bearings.

Thermometers

T_1—Steam at stop valve.
T_2—Final feed.
T_3—Condensate pump discharge.
T_4—Oil to bearings.
T_5—Oil from bearings.

Flow Indicators

F_1—Steam flow indicator.
F_2—Raw water to evaporators.

Water Level Indicators

WL_1—Surge tank level.
WL_2—Storage tank level.
WL_3—Raw water tank level.
DI—Condensate leaving condenser (Dionic water indicator and alarm).
OLI—Oil level indicator.
K—Condenser vacuum (Kenotometer).

RT—Resistance temperature indicator (distance thermometer D_1, D_2, D_3, etc.).

Steam Supply. Steam flow indicator and recorder, temperature indicators and pressure gauges. The steam pressures after the governor valves and in the first stage of the turbine will serve as a

check on the observed steam consumption. The turbine nozzles, if clean, function as steam meters.

Feed Water Supply. Condensate recorder, temperature indi-

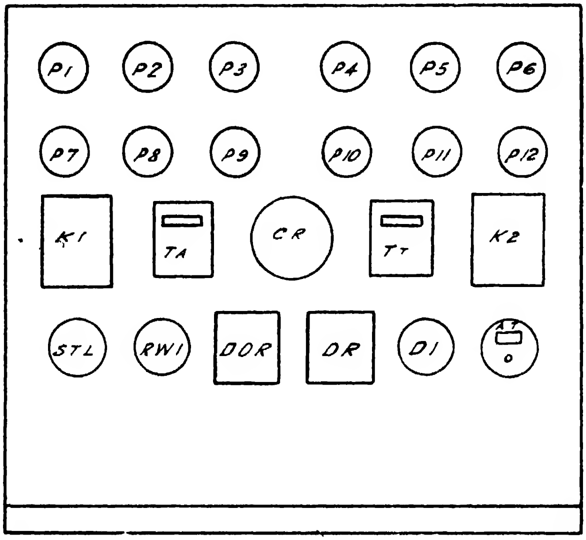


FIG. 304. Typical Turbine Gauge Panel.

P_1—Steam before stop valve.
P_2—Normal—after regulator valve.
P_3—Overload—after by-passing valve.
P_4—Steam to No. 2 H.P. feed heater.
P_5—Steam to No. 1 H.P. feed heater.
P_6—Steam to L.P. feed heater.
P_7—Main oil pump outlet pressure.
P_8—Auxiliary oil pump outlet pressure.
P_9—Motor-driven flushing oil pump outlet pressure.
P_{10}—Bearing oil pressure.
P_{11}—Pilot oil pressure.
P_{12}—Oil pressure at cooler outlet.
K_1—Kenotometer (vacuum at condenser inlet).
K_2—Kenotometer (vacuum at condenser outlet).
C.R.—Condensate recorder and integrator.
T.A.—Alternator temperature indicator.
T.T.—Turbine temperature indicator.
S.T.L.—Surge tank level indicator.
R.W.I.—Raw water to evaporator, integrator.
D.O.R.—Dissolved oxygen recorder and indicator.
D.R.—Dionic recorder and indicator.
D.I.—Service water tank level indicator.
A.T.—Alternator air temperature alarm.

cators, dissolved oxygen recorder, dionic water tester, surge and storage tank level indicators, etc.

Raw Water Supply. Indicators and integrators for water supply to evaporators and tank level indicators.

Cooling Water Supply. Temperature indicators.

Oil Supply. Oil tank lever indicator, temperature indicators, pressure gauges (local bearing thermometers of either the stem or dial types are useful).

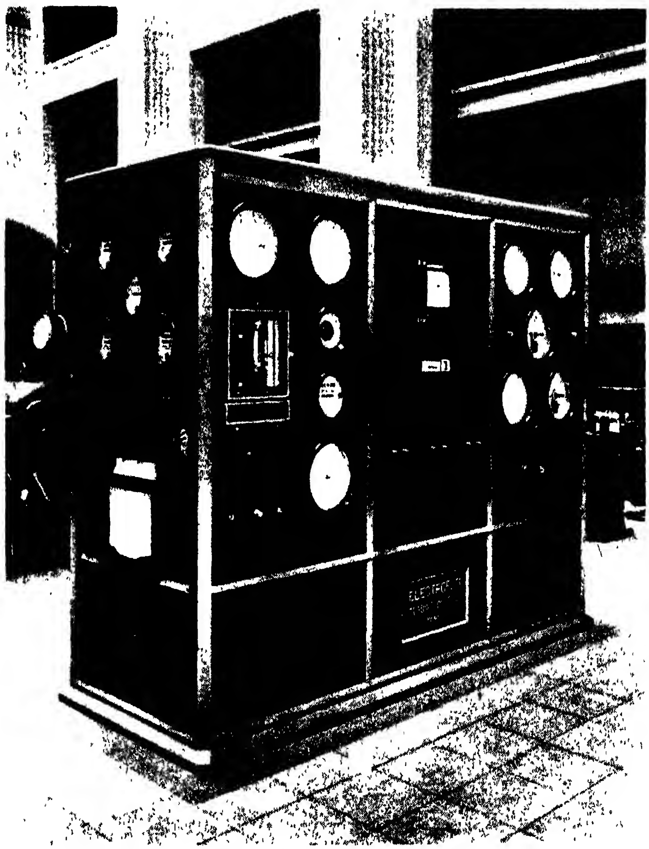


FIG. 305. Turbine Control Panel, Battersea Power Station.

An electrical alarm either visible or audible giving warning of low bearing pressures or high oil temperatures may be included. Whilst not directly under oil supply it is convenient to mention the tachometer which is usually fitted at the turbine end.

Vacuum. A vacuum dial gauge and a kenotometer are the usual instruments for the condenser. A kenotometer is a mercurial vacuum gauge, and two of these instruments may be used, one

connected to the inlet and the other to the outlet of the condenser (air suction). Care should be taken to keep the mercury out of the condenser. A coil of tubing is included to trap any condenser vapour and also prevent it from accumulating above the mercury in the tube. One vacuum dial pressure indicator or gauge is placed on top of the condenser and in such a position that it can be easily seen from the turbine house basement. A vacuum gauge has the advantage that it gives an indication of the vacuum obtaining before the mercury begins to fall (or rise) in the kenotometer. This is particularly helpful should vacuum be falling during an emergency, since the turbine driver can then take steps to shut off the machine in the event of failure of the steam unloading devices.

If the exhaust steam from the turbine is not superheated a thermometer may be used instead of a dial or mercurial gauge. The fixed relationship between pressure and temperature of saturated water vapour enables the exhaust pressure in absolute units to be determined from steam tables when the exhaust temperature is known.

Alternator Windings and Air Circuit. Temperature detector equipment for the stator windings and air circuit, and a temperature alarm for the air cooler are usual. The stator temperature indicator may be either mounted on the alternator panel in the control room or the turbine gauge panel in the turbine house. The latter appears to have advantages in that the cost of the special multicore cable is reduced and the turbine driver has the alternator temperature indicator and air temperature alarm equipment under observation.

In some stations a synchroscope has been included in the turbine gauge panel and is useful for the turbine drivers. The disadvantage is the cost of voltage leads from the control room, although if these are at hand it is justifiable to include an indicating wattmeter on the panel. An alternative to the wattmeter is a load ammeter, which necessitates a current transformer in one phase of the alternator block connections.

Turbine Temperature Indicator. This permits of centralised temperature control of the numerous points of measurement required on a turbine. The connecting cables to each point may be either two- or three-core, usually V.I.R. or alternatively Pyrotenax, the size depending chiefly on the length of route. The services catered for are steam, water and oil, the tube material for each being steel, gun metal and copper respectively.

The following relate to an 18-point distance thermometer for a 30 MW turbine :—

1 . . Before turbine stop valve.
2 . . Steam entering condenser.
3 . . Air suction.

Condensate outlet—
4 . . Condenser.
5 . . Ejectors.
6 . . Drain cooler.
7 . . L.P. heater.
8 . . $H.P._1$ heater.
9 . . $H.P._2$ heater.

Oil cooler—
10 . . Oil inlet.
11 . . Oil outlet.
12 . . Water outlet.
13 . . Air cooler water outlet.

Main cooling water—
14 . . Inlet No. 1.
15 . . Inlet No. 2.
16 . . Condenser outlet No. 1.
17 . . Condenser outlet No. 2.
18 . . Surge tank.

Alternator Temperature Indicator. This is a similar instrument to that used for the turbine except that thermo-couples are used.

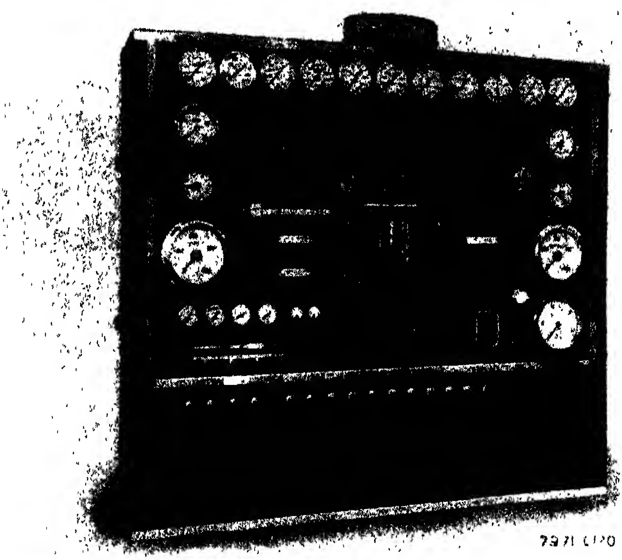


FIG. 306. Turbine Control Panel, Brighton "A" Power Station.

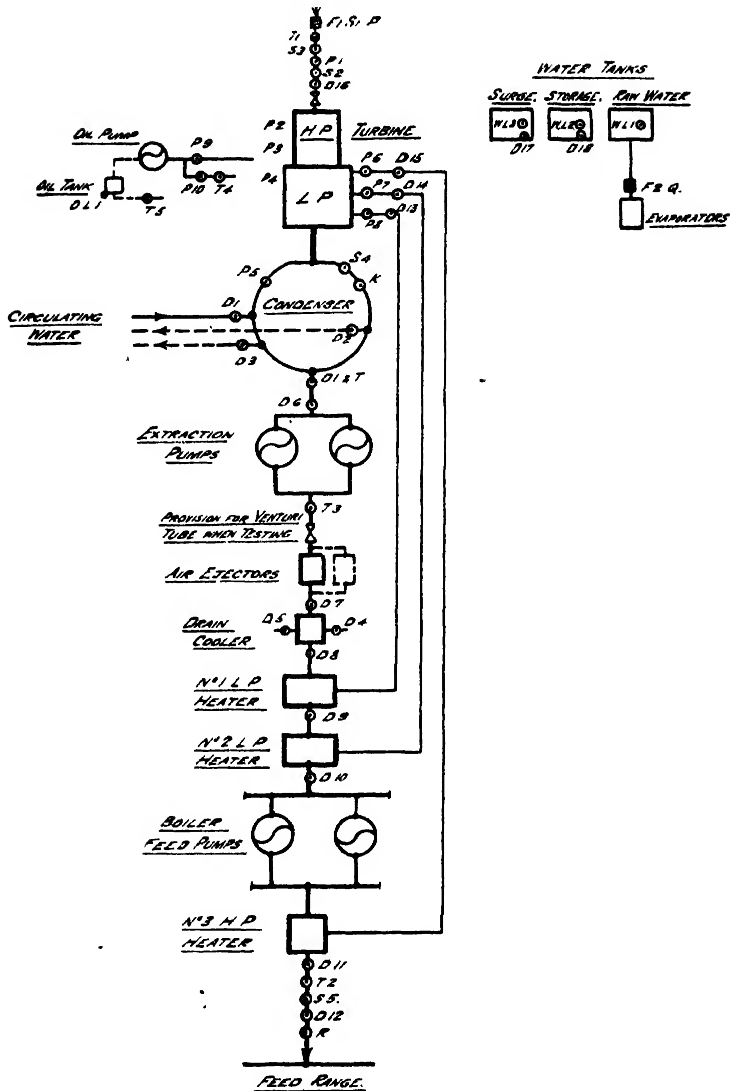


FIG. 307. Points of Measurement in Steam, Water and Oil Circuits.

The points of measurement vary according to manufacturers requirements :—

30 MW, 11 kV. alternator . .	24-point indicator
30 ,, 33 ,, ,, . .	12 ,, ,,
50 ,, 11 ,, ,, . .	6 ,, ,,

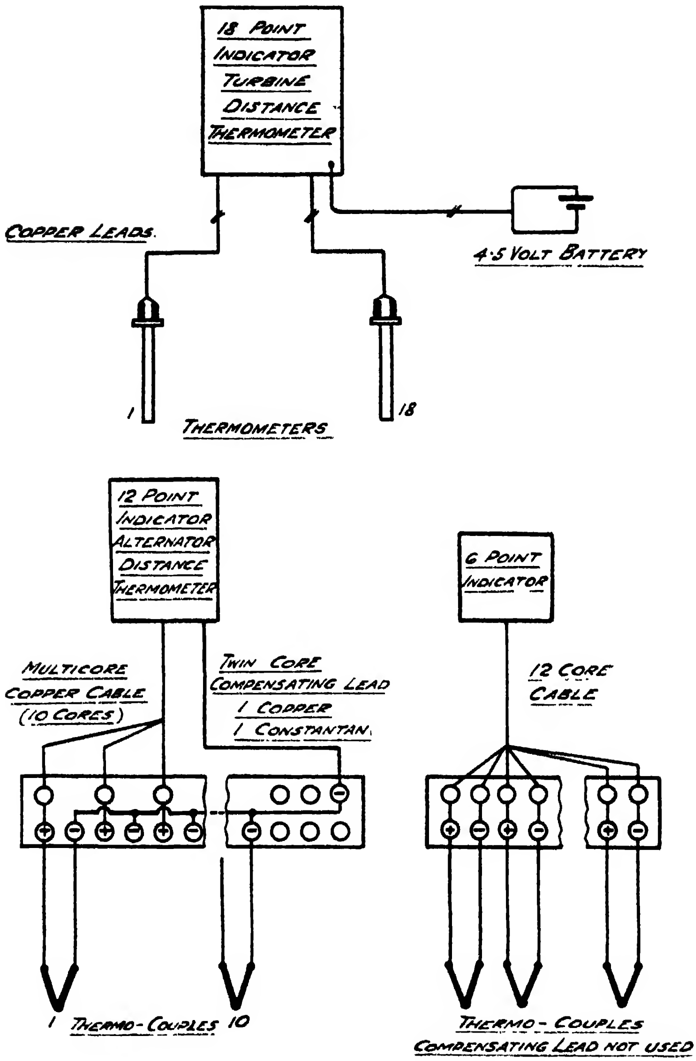


FIG. 308. Temperature Indicators.

The points of measurement for a 33 kV. machine were

1 core conductor,	2 core conductor,
3 stator tooth,	4 stator core,
5 stator core,	6 stator core,
7 end winding,	8 end winding,
9 inlet air,	10 outlet air.

The embedded temperature detectors are fitted near the neutral connection ends of phases, the leads from the detectors being taken to a terminal box fitted on the alternator. The embedded detectors (thermo-couples) may consist of $\frac{1}{4}$ in. wide strips of copper and constantan, mica insulated.

A compensating cable may be dispensed with but then it is necessary to run each core to the instrument. A more costly cable is required but in the former a fault on the common core puts the instrument out of service. It is also claimed that a more accurate reading is obtained by using a lead and return for each point instead of a common return. The temperature of each point is logged, the switch being normally left at the position connecting up the hottest

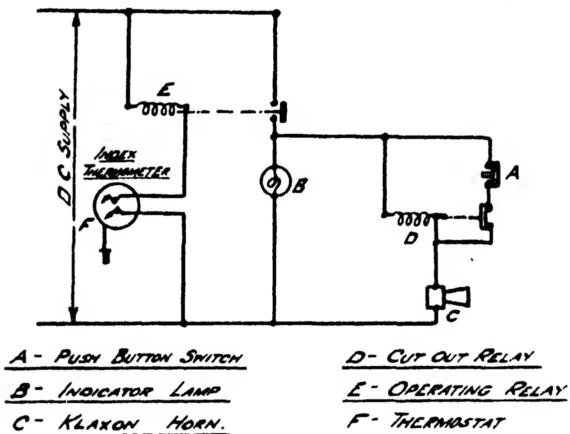


FIG. 309. Air Temperature Alarm Equipment.

point on the stator so that any abnormal increase in the temperature can be observed.

An instrument may be provided for indicating the average rotor winding temperatures. Usually not less than two special brushes are included on each slip ring of the rotor for this purpose.

Alternator Air Temperature Alarm. This may be mounted on a separate panel or included on the turbine gauge panel. A typical equipment is shown in Fig. 309. The alarm pointer on the index thermometer is set to a predetermined temperature of about 155° F. and if the air temperature exceeds this value audible and visible warning will be given on the alarm equipment by a klaxon horn and lamp. The horn may be stopped by the push button but the lamp remains connected until the temperature is reduced below the value at which the alarm is set.

Dissolved Oxygen Recorder. The presence of dissolved oxygen in feed water is responsible for the corrosion of boiler tubes and impairs condenser performance. This corrosion is chiefly due to the presence of oxygen in solution in the condensate, and de-aerating plants are included to reduce the concentration of oxygen. It is

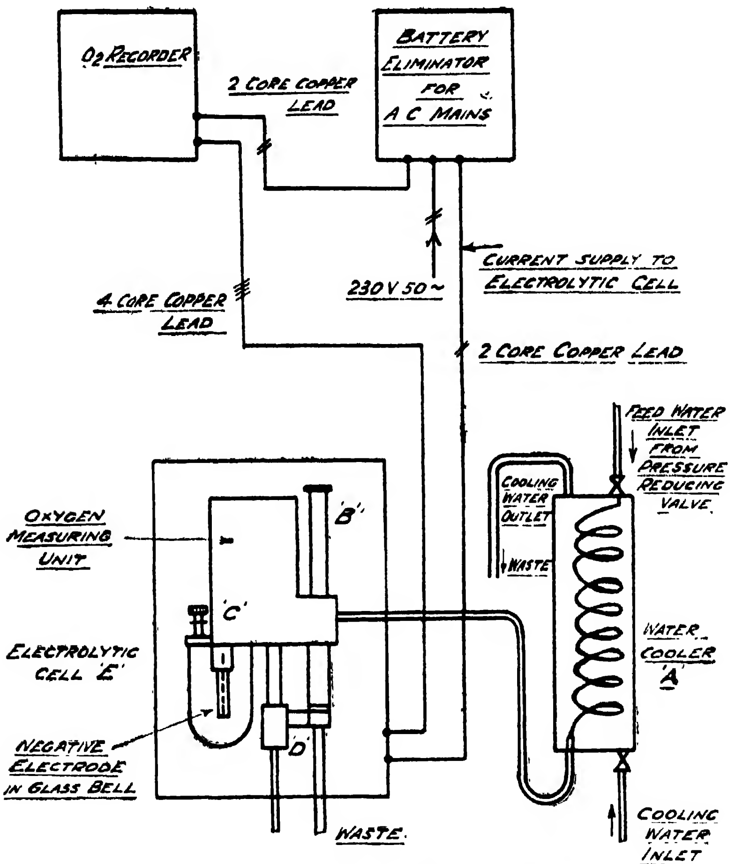


FIG. 310. Cambridge Dissolved Oxygen Apparatus.

difficult to eliminate the dissolved oxygen entirely from the system but it is essential that a value of 0·10 c.c. per litre should not be exceeded. The chief causes of increase in oxygen content are leaky valves and defective seals on pumps and other auxiliary plant. The outfit included can be arranged to work with either a recorder or an indicator, or a combined equipment. Two ranges are available

for either the recording or indicating units, namely, 0 to 0·50 c.c. dissolved oxygen per litre or 0 to 1·00 c.c. per litre.

The Cambridge dissolved oxygen recorder will be understood from the notes and Fig. 310.

The water to be analysed enters the cooler A from a high-pressure valve. It is here reduced in temperature to about 20° to 25° C. and then passes on to a constant head device B which maintains the correct flow of water through an orifice situated in a water jacket C surrounding a katharometer. The water then flows down the contact D where it comes into intimate contact with hydrogen gas, dissolving some of this and giving up part of its oxygen. The hydrogen is generated in the electrolytic cell E, passes the first side of the katharometer and then flows through compensator and restriction to the contact chamber. The second side of the katharometer is exposed to the gas in the chamber. The katharometer consists of four platinum spirals mounted in cells in a central metal block and connected together to form a Wheatstone bridge. Two of the cells are open to the pure hydrogen and two to the gas from the contact chamber. The spirals are heated by an electric current, and when the same gas surrounds all four they attain the same temperature and no deflection of the galvanometer in the indicator or recorder takes place. If, however, one pair of spirals is exposed to hydrogen and the other pair to a mixture of hydrogen and oxygen in the contact chamber, the temperatures of the two pairs of spirals will differ and a deflection of the galvo will be caused which is proportional to the amount of oxygen in the mixture. The concentration of oxygen in the gas in the contact chamber is proportional to the amount of oxygen dissolved in the feed water passing through the chamber. The galvo scale can therefore be calibrated to read directly the dissolved oxygen content of the feed water.

In the Weir corrosion detector the feed water passes over a polished steel plate, steam being admitted to the other side. Corrosive gases in the feed water attack the hot steel and this action is observed and the cause can be investigated.

De-gasers may be installed in the feed water system to reduce the oxygen content. These are containers holding loosely-packed iron turnings which absorb the oxygen and periodical cleaning removes the iron oxide formed. De-aerators are discussed in Vol. 2.

Water Purity Meters. The most likely source of ingress of foul water is through the condenser by way of leaky tubes. The cooling water may be obtained from the sea, tidal rivers, rivers contaminated by dye-works outfall and acid, and sewage works. Priming, corro-

sion and excessive scaling of tubes in the boilers are troubles likely to result from contamination. Contamination of the feed water may also be caused by evaporator priming, particularly at reduced loads.

If cooling water is taken from the sea or a tidal river and the water is salt, then a silver nitrate test on a sample of feed water indicates any leakage. A continuous record of the salt present may be made by a recording salinometer.

Stations using fresh water and sewage effluent for cooling purposes generally employ a " dionic " water tester. This instrument is a reversed ohmmeter and measures the conductivity of the water sample. The presence of undistilled water (cooling water leaking to the steam side of the condenser) is immediately detected. When installing a new instrument past records of condensate conditions are helpful for calibration purposes. The conditions of the tubes, *i.e.*, clean or otherwise, free from leaks, etc., together with the best possible record of " dionic units " appertaining to that condition.

The principle of operation is based upon the fact that the electrical conductivity of a dilute aqueous solution is a measure of the dissolved inorganic impurity in that solution. A portable instrument may be used, but a recording outfit to each turbine and an indicating instrument with alarm device may also be provided.

The instrument consists of a water conductivity tube (through which a sample of the water under test is continuously flowing) and a meter of the indicating or graphic recording type. The apparatus is operated from direct current mains. The indicating meters consist of specially constructed ohmmeters.

Where the nature and composition of the impurity is variable it is not practicable to calibrate the instrument in terms of the impurity and the scale is usually calibrated in terms of the conductivity units actually measured, the interpretation of the readings being left to the chemist.

Another use of the electrical conductivity method is the determination of the carry-over of boiler water in steam to the superheater and turbine. Excessive carry-over may cause the failure of superheater tubes and, even with a small amount of boiler water in the steam, corrosion and loss of turbine efficiency have been noted.

In this method steam is sampled between the boiler outlet and the superheater, passed through a reducing valve and cooling coil and fed to the " dionic " meter which gives a continuous record of the electrical conductivity and so of the purity of the condensed steam.

Some typical values of conductivity obtained with Dionic instruments are given :—

Distilled water	6·0	units.
Condensate of boiler feed	0·9 to 5·0	,,
Cooling water—		
Tidal river	550 to 1,200	units
Estuary	1,000 to 55,000	,,
Water towers	3,000 to 4,000	,,
Sea water	50,000	,,
Public water supplies	34 to 420	,,

The conductivity is at 20° C.

In one station the general practice is to test for condenser tube leakage when the " dionic " figure exceeds 4 units.

Barometer. A standard barometer is a very useful instrument and should be included under station instruments.

Shaft Eccentricity Indicator. Probably one of the most frequent causes of turbine failure has been mechanical damage caused in the first instance by the rubbing of rotating parts on fixed portions, initiated usually either by shaft eccentricity or by undue differential thermal expansion between the casing and the rotor. Turbine shafts for high-pressure rotors have usually been of the " flexible " type, but there is now a trend towards using what is known as the "stiff" shaft in which normal operation is entirely carried out below any critical speeds. The flexible shaft is liable to " hogging," if it is allowed to be run up or slowed down incorrectly. The measurement of shaft eccentricity can be carried out by means of an electro-magnetic indicator, applied to the outboard end of the high-pressure bearing. The eccentricity indicator does not itself record as great an amplitude as that of the eccentricity of the centre point of the rotor but it can be calibrated in terms of this latter value. It has been suggested that an instrument employing optical principles might well be used.

Differential Expansion Indicator. As the size of turbine increases, the mass of casing—which is fixed by the steam pressure and temperature—tends to increase at a greater rate than that of the rotor. There is therefore an increased possibility of differential expansion between these two components, leading ultimately to the danger, under certain operating conditions, of failure through rubbing of the fixed and moving blades. Two types of indicator are available. One is of an electro-magnetic type similar to that used for the eccentricity indicator (500 c.s. supply), but operating on a disc on the rotor shaft with one detector on either side. This disc can be

placed immediately outside the inner bearing of the high-pressure rotor. The second type employs a beam of light from a focused lamp mounted on a pedestal at one side of the machine, with the beam cutting across the disc on the rotor shaft. On the " receiving " side of the machine, a small screen is provided so that the magnified image of the disc in relation to the calibrated gauze can be observed. A third type of instrument is an elaboration of the total expansion indicator fitted at the foot of the first high-pressure bearing. It comprises an electro-magnetic device in which the movement of the pedestal is conveyed to a plunger passing between two coils, which form the arms of a bridge circuit.

Vibration Indicator. Portable vibration-measuring instruments have been chiefly used in the past but the trend is towards the provision of permanent indicators. These comprise either electromagnetic or piezo-electric detecting units fitted at various parts of the machine.

Casing Temperature Detectors. It has been suggested that it should be an advantage to have at least three to five thermo-couples attached to the cylinder casings to enable the operatives to detect undue heating or cooling in any particular zone. One at each end of the top portion of the high-pressure cylinder, and one at each end of the lower portion would appear to be suitable. Under certain conditions of operation the steam may be cooler than the machine, particularly in unit plants, and dangerous internal temperature conditions may obtain.

Brush-Ljungstrom Turbine

The arrangement of the blade system is such that the radial blading of one disc is interleaved with the radial blading of the other disc, the blade rings being fixed concentrically to each disc.

Each steam rotor is coupled to an alternator which carries half of the load. A special feature is that the entire turbine is mounted on the condenser, the turbine casing being bolted to the condenser by means of a heavy exhaust flange, and the two alternators which overhang are bolted to the ends of the turbine casing. The weight of the overhung portion is taken by means of springs and considerable saving in foundations is effected. The exciter which serves both alternators is overhung on the shaft of one of the alternators.

The blades are secured by a dovetail fixing to a strengthening ring which is connected to the blade disc by a special expansion ring, the dumb-bell construction of which allows expansion and contraction without distortion. The blades are shrouded by a

further strengthening ring. The fine clearances between each ring are between the strengthening rings of any one blade ring, and thin nickel strips caulked into strengthening rings of the next smaller blade ring. Any accidental contact will therefore only cause slight wear to the nickel strip. Labyrinth steam packings are provided to prevent leakage along the shafts and also between the rotating blade discs and the stationary steam. The general constructional features will be noted from Figs. 311 to 314.

The turbine has no high-pressure casing. The complete blade

FIG. 311. Section of Single Blade Ring. (Brush Electrical Eng. Co. Ltd.)

1—Blade disc.
2—Seating ring.
3—Caulking strip.
4—Expansion ring.
5—Rolling edges.
6—Rolling edges.
7—Nickel packing strips.
8—Caulking strips.
9—Strengthening rings.
10—Dovetail profile.
11—Blade.

system is housed in an unlagged low-pressure casing which is only exposed to the temperature of the exhaust steam. The steam enters the turbine through the emergency stop valve and the governor controlled throttle valve and then flows through internal pipes to the forged steam chests which are situated one on each side of the blade system. Each steam chest has concentric annular compartments which communicate through holes in the labyrinth packed balancing discs and in the turbine discs themselves at different stages of the blading. The main steam supply at the most economical load passes from the inner compartments of each chest to the inside of the first ring through holes in the hubs of the discs.

The next two connections, one from each chest, are used for

admission of additional steam from the middle compartments to lower pressure stages of the turbine to enable maximum continuous load to be carried. Others are used for bleeding steam to the high- and low-pressure heaters. The outstanding features of the design

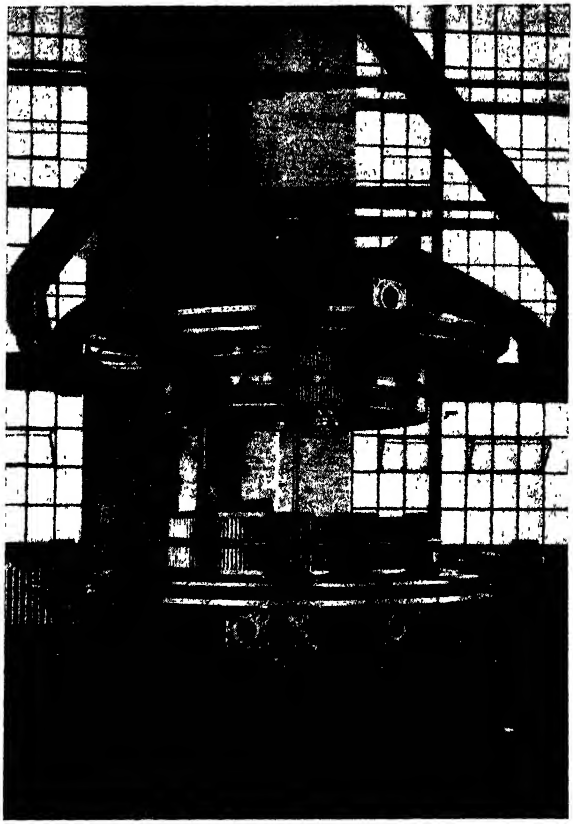


FIG. 312. Blade System ready for Assembly. (Brush Electrical Eng. Co. Ltd.)

is that there are no stationary blades, this being made possible by the use of radial steam flow instead of the usual axial arrangement and the relative speed of the blades is twice that of the running speed and more efficient conditions of steam flow are possible. The blade system fixed to one wheel rotates between the blade system of the other wheel, the two systems rotating in opposite directions. Thus there are no stationary guide blades and the relative speed between the blades is twice that of a system working with stationary

blades. The quality factor is four times greater than if only one wheel had been rotating. It gives a value equal to, if not higher than, that for multi-cylinder axial flow turbines. Blade length is adapted to the volume of steam. Where the volume of steam in the final stage becomes very great, as in large units, each turbine wheel is further provided with one or two rows of radial blades for the last expansion step. These blades work together with the stationary blades fixed to the turbine casing. This design gives an exhaust area equal to that of an axial flow turbine with double outlet.

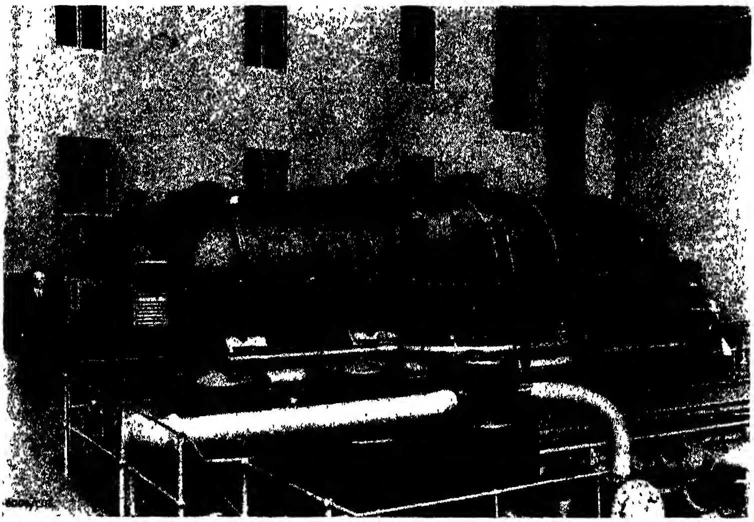


FIG. 313. 37,500 kW., 1,500 r.p.m., Turbo-Alternator, Brighton "A" Power Station. (Brush Electrical Eng. Co. Ltd.)

Neither of the two rotating systems have bearings of their own, each being firmly bolted to extensions of the alternator shafts. The thrusts which are fitted at the extreme ends of the alternator shafts, serve to preserve the turbine rotating elements in their correct axial positions. The chief advantages claimed for this design of machine are :—

(1) Small and simple foundations.

(2) Light weight of construction allows the material to follow quickly any changes in temperature.

(3) Can be started up rapidly.

(4) Radiation losses are low since the casing is only subject to exhaust temperature, lagging being unnecessary except for the high-pressure steam chests and control valves.

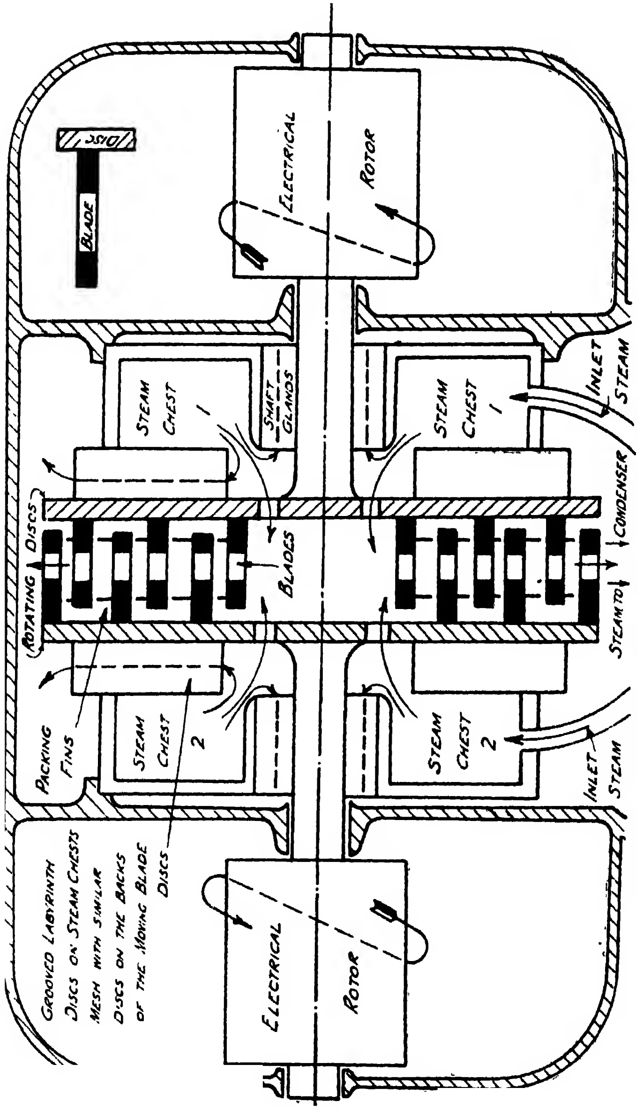


Fig. 314. Steam Flow Diagram for a Double Rotation Turbine.

Possibly the largest machine of this type at the present time is 65 MW, 1,500 r.p.m. operating at 200–280 p.s.i. at 660–750° F. There are two such machines in the Västeras Station in Central Sweden. At the final acceptance tests a thermo-dynamic efficiency of 90·3 per cent. was obtained.

Turbo-Alternator Operation

Starting Up

The layout and types of turbo-alternators are so varied that only the fundamental operational features will be considered. It is assumed that the steam ranges are charged and ready to afford supply to the turbine. The order in which some of the non-essential or minor auxiliary plant may be put into operation can usually be varied to some extent without in any way affecting the turbo-alternator. In power station operation safety to personnel is of primary importance, and when starting a machine it is always essential to ascertain that all maintenance and operation men are clear. Experience has shown that danger is less when a machine is about to be run up and put on load than when it is on the turning gear and left in readiness for subsequent starting.

Shaft turning, rolling or barring gear is now generally fitted to all turbo-alternators of 15 MW and above, so that it is necessary to start this auxiliary before proceeding with running up of the set. The steam auxiliary pump can be started or, alternatively, the low-pressure electrically-driven flushing pump will serve to provide an adequate supply of oil to each bearing and the rolling gear. The high-pressure or jacking oil pump can then be started, and the bearings checked to ensure that there is a supply of high-pressure oil to each. The rolling gear can be engaged, but care is required not to attempt to mesh the gears with the driving motor or turbine running. The maker's instructions should always be followed. It is necessary to see that the thrust adjusting gear is in the " off " position. When the shafts are rotating, the high-pressure oil pump can be shut down.

Adequate drainage from all steam paths is essential, and the removal of all water from cylinders and pipes must be ensured before the turbine is started. Therefore, the first major operation is to open all drains from the steam receiver to the turbine steam chest and its associated pipework. Fig. 315 shows a typical steam pipe arrangement for large turbines. The steam chest and cylinder interconnecting pipe drains can be opened to atmosphere, and all turbine and feedheater steam pipe drains to the condenser. After clearing the chest, cylinders and interconnecting pipes of water, the atmospheric drains should be closed, and the drain connections opened to the condenser. In some plants an isolating valve is included in the main steam pipe and located near the steam chest, whilst others provide an isolating valve on the main steam receiver

only. In all makes of large turbines some form of oil-operated stop and emergency steam or runaway stop valve is provided. In the Parsons machine it is necessary to screw down the hand-controlling gear of this emergency valve in order to close the actuating piston drain ports. The emergency trip is then set by depressing the plunger

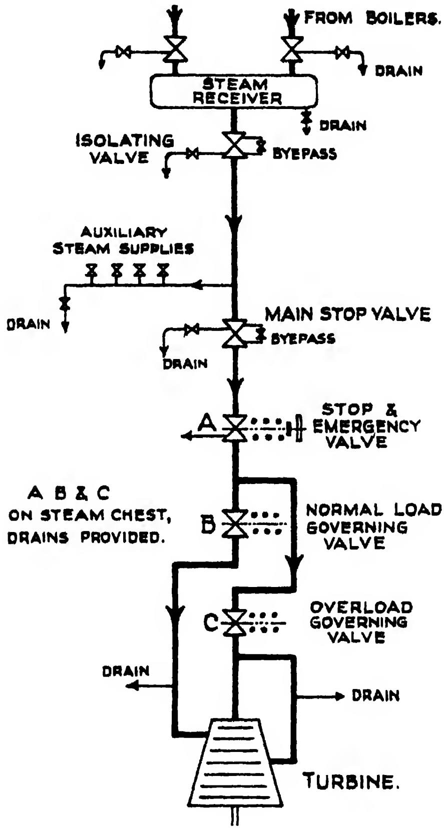


Fig. 315. Typical Arrangement of Turbine Steam Pipework.

mounted on the steam end keep. This allows the relay oil pressure to build up under the pistons of the stop and emergency valve and also the governor steam valves. The latter valves should lift to their full extent. The stop and emergency valve can then be fully opened by operating the hand emergency tripping lever located in the steam end door of the turbine. The valves should be checked to ensure that they have closed correctly. Note that the trips are reset.

The circulating water can now be passed through the condenser by opening the main inlet and outlet valves and, at the same time, opening any air cocks fitted to the water boxes of the condenser. Where unit circulating water pumps are installed, or another pump has to be started, it may be necessary to prime the pump. If the pump is working on a syphonic system, the pipe line will require clearing of air by the ejector provided. From the condenser gauge-glass it should be noted that adequate condensate is available, when the suction valve of one of the extraction pumps can be opened and the motor started. The discharge valve of this pump can be opened, and also the condensate re-circulating valve, and the automatic feed control valve if one is fitted to the condenser.

After the distribution box and piping has been drained, the turbine glands can now be packed with steam. The steam supply to glands should be gradually increased as the vacuum improves, so that some steam is always leaking outwards.

The steam supply to the main and booster ejectors can be given. Booster or quick-start ejectors are capable of raising vacuum to the turbine starting value in about three to five minutes. Coupled with the use of turning gear, this ensures that turbine shaft distortion is unlikely to occur during the starting period. Whilst vacuum is being raised, all steam pipe, chest and turbine casing drain valves should be checked and left fully open. During the running up period some 3 to 4 tons of water may be formed by condensation. When the vacuum has been raised to 20 in. Hg. the booster ejector can be shut down by first closing the air suction valve and then the steam supply valve. If a three-stage ejector is provided, steam is applied to the third stage, and when the condenser vacuum reaches 15 in. Hg. steam can then be admitted to the second stage, and, at 20 in. Hg., to the first stage of the ejector.

The by-pass valve on the main stop valve (if one is fitted) can be cracked open, and when the line is warmed through to the stop and emergency valve, the by-pass valve can be fully opened. Condensate, by way of the recirculating pipe, should always be passing through the air ejector, otherwise the inter-cooling condensers will heat up and may be damaged. Next crack open the stop and emergency valve, and allow sufficient steam to flow to the turbine for warming up purposes. The steam admitted should not permit the turbine to overtake the turning gear speed. If the turning gear has not disengaged when a vacuum of 20 in. Hg. has been reached, the stop and emergency valve can be slowly opened until the gear disengages. The set can then be allowed to turn slowly for about

a quarter of an hour. The set can be run at about 250 r.p.m. for fifteen to thirty minutes according to the size of the machine. Some water can be passed through the alternator oil cooler, the air cocks being opened to free the cooler of air. Should the starting of the set be delayed beyond the normal time, precautions should be taken to drain the main steam pipe and steam chest before attempting another start.

If separate ventilating fans are installed, one fan can be started before the set is run up to speed. By starting up a fan late and shutting it down early it is contended that this procedure avoids subjecting the stator and, in particular, the rotor windings to wide temperature limits. It should be noted that the exciter field switch, usually mounted on the machine panel in the control room, is open, and that the exciter field rheostat is in the " all-in " position before running the set to full speed. If these items are forgotten and the set is run up without cooling air, it is possible for overheating to take place. The fan dampers should, of course, be opened.

The governor regulator should be screwed back to the limit of the " lower " position. Check that the extraction pump discharge line is open. The speed can be gradually increased in easy stages of about 40 r.p.m. by slowly opening the stop and emergency valve, taking from, say, a quarter to half an hour or more if desirable. The governor will usually take control at about 5 per cent. below full speed, and when this stage is reached, the stop and emergency valve can be fully opened. The set can now be brought up to full speed by rotating the governor sleeve regulator in the " Raise " direction. Should an isolating valve (main stop valve) be provided, it is advisable as a safety measure to keep this only about one-quarter open, so that it can be closed quickly in the event of any untoward happening during starting. Note that when the main mechanical oil pump commences to deliver oil, the steam turbine-driven auxiliary oil pump automatically cuts out by means of its regulator. As a guide, a set may be kept rotating slowly for a quarter of an hour at a speed of from 200 to 300 r.p.m., so that the steam rotors are uniformly heated. After this, the speed can be increased by increments of up to 10 per cent. of the normal speed, but care is required if one of these speeds should correspond with the critical speed of the set. It is advisable to pass through such a period rather more quickly. If excessive vibration occurs, probably due to unequal heating, the speed should be reduced until the vibration disappears. In some cases it may be necessary to shut the set down and start afresh. The steam chest and interconnecting pipe drains to the

condenser can be closed, and opened to their respective steam traps. The isolating valve can be opened and its by-pass valve closed.

Bearing oil temperatures should be watched during this period and on approaching normal working temperature. Some cooling water can be passed through the oil coolers, and after the oil has warmed up to 120° F., or thereabouts, the inlet and outlet water valves can be fully opened. Keeping the water shut off the coolers ensures that the oil reaches working temperature more quickly and reduces the risk of vibration due to shaft "climbing." At this stage, a general check over the set and its auxiliaries is recommended to ensure that the vacuum is being maintained, oil supply to all bearings, gland steam supply adjusted, and that the set and all its auxiliaries are functioning satisfactorily. The driver can then signal instructions to the control engineer that the set is ready for synchronising.

The set should not be run for long periods without load. As the electrical load is put on the set the condensate recirculating valve can be closed, and also the H.P. cylinder drain. If two fans are included, the second one can now be run.

A set may be started up and put into commission with or without the feed-heating plant. The heater air relief and drain valves must be opened before steam is admitted. The low-pressure heaters are put into operation first. Some attention is necessary in the operation of the thrust adjusting gear which is required to take care of the unequal expansion of the turbine cylinder and shaft during warming up. If this adjusting gear were not provided, the turbine blade shrouding would bear heavily on the contacts and be unduly worn. This would result in increased blade clearance during normal running, and therefore increase the steam consumption. The turbine must be off contacts before either stopping it, and also before putting it on the rolling gear. The makers' instructions should always be followed. If the machine has been shut down for a few hours, the thrust gear may be adjusted to about the halfway mark whilst running up to speed, and gradually pulled right up as soon as the machine is carrying about half-load, or has been running for a sufficient period of time to have become thoroughly warmed. The time taken primarily depends on the shut-down period and the rapidity with which load is applied, but, in general, half an hour is ample after an overnight shut-down. When running on light load for some time after starting, the thrust gear must not be pulled hard up. Should the load be reduced to a low figure, or the steam temperature varies from normal for some considerable time, the

thrust gear must be eased off a little. As a guide, if a set is cold at starting, the thrust may be pulled up halfway after three-quarters of an hour, and three-quarters after three hours. It should not be pulled right up until the turbine is thoroughly warmed through. The expansion indicator will show the position and serve as a check.

It is advisable to inspect the air cooler chamber to ensure that there are no leaking tubes. If the cooler surface is covered with moisture and the tubes are sound, this will be due to leakage of air which is cooled below its dewpoint. The cooler surface can be dried by shutting off the water supply and opening the emergency inlet and outlet doors in the alternator foundation block. The air circuit alarm device can be tested by turning the adjustable pointer until it touches the indicating pointer, when the alarm and signal lamp will operate. Then reset to its original position, which is usually about 120° F.

Synchronising. The control room engineer will be aware of the switching operations required. The main circuit-breaker and voltage transformer will be racked into position, and the neutral earthing circuit-breaker closed (if one is provided). The exciter field switch, which may be in either the pilot or main exciter circuit, can be closed after noting that the exciter field rheostat is in the " all-in " position. Gradually cut out the field rheostat, thereby allowing adequate time for the main a.c. voltage to build up. The speed of the set can be adjusted as desired by operating the remote-controlled governor motor until its frequency corresponds to that of the sets already on the bus-bars. The plug for " On-Load " can be placed in receptacle of a set or feeder on load, and the " Incoming Machine " plug into the receptacle of the set about to be put on the bus-bars. Switch on the synchroscope and the lamps will be seen to go in and out in phase with the 'scope. They may be arranged to be bright or black when the 'scope pointer is vertical (see Chapter XIV, Vol. 2). Withdraw " Incoming Machine " plug and insert it in another panel of a set already on the bus-bars. The 'scope pointer should then be at the top, and all the lamps black or bright, as the case may be. Should the synchroscope equipment fail and it is necessary to get a set into commission, then it would be possible to do so by plugging two lamps across the two synchroscope plugs and using them for this purpose. The " Incoming Machine " plug should be replaced on the incoming set control panel, and the speed of this set can be adjusted by means of the governor gear until the 'scope pointer is moving very slowly in either direction marked " Fast " or " Slow". An alternator can be

synchronised satisfactorily with the 'scope moving in either the "Slow" or "Fast" directions. The advantage of synchronising with the incoming set "Fast" is that it will automatically pick up a small load. The incoming set should be switched on the bus-bars just before it reaches instantaneous synchronising and while it is ahead of the running sets. It then drops smoothly into phase as it picks up load. The advantage of bringing the incoming set in "Slow" is that it will trail-in, which is useful when the steam pressure is low. Synchronisation is attained when the pointer remains stationary at the twelve o'clock position. When the pointer is vertical and remains stationary with the lamps black (or bright) the main circuit-breaker control switch can be operated, thereby closing the circuit-breaker. The red indicating lamp will light and the green lamp will be switched off. Immediately after synchronising the 'scope should be switched off.

Electrical load can be gradually applied to the set by speeding it up, *i.e.*, opening the governor valve by means of the remote governor motor control. The rate at which load is applied has already been mentioned earlier in this chapter, but a general rule is about 1·5 MW per minute.

Before proceeding with synchronising, it is often well worth while noting that the closing and tripping circuits are in order. The voltage regulator can now be put into commission, and the instructions vary according to the type of regulator used.

Normal Running. The bearing temperatures should be noted and should not normally exceed 150° F. Oil pressure should be maintained at between 12 and 15 p.s.i. Turbines running for long periods should have their governor emergency and stop valve spindles eased a few turns to prevent stickiness. The alternator outlet air temperature should be noted, and will generally be about 120° F. maximum. Vacuum and corresponding circulating water temperatures should be noted, and a Dionic recorder will show any tube leakage resulting in impurities mixing with the condensate. The oil tank drain should be opened and the amount of water taken off noted.

Shutting Down. The voltage regulator can be taken out of circuit (or left until the load is removed), at the same time noting the power factor meter and the exciter field ammeter. The load can be taken off by operating the governor control switch in the "Lower" position, at the same time keeping the power factor adjusted. Before the load is completely removed, the thrust adjusting gear must be returned to the "Off" position. No load

on the set will be reached when the integrating wattmeter ceases to rotate, and the main circuit-breaker control switch can be turned to the " Off " position, thus tripping the breaker. The green lamp will then be illuminated. To check the electrical protective gear circuits, the relay can be hand-operated, and this is normally arranged to open the main circuit-breaker and the field suppression-breaker simultaneously (see Chapter XVIII, Vol. 2). In some plants the main circuit-breaker opens first, and then the field breaker, whilst in others they both open together, but the field-breaker may lag slightly. The former arrangement ensures that the alternator does not operate momentarily as an induction machine above synchronous speed due to loss of field. Under this condition, a large wattless current may be taken from the system, and if small sets are left on the system they may well be overloaded. After the main circuit-breaker has been opened, the stop and emergency valve can be tripped by means of the emergency hand lever mounted near the steam end of the turbine. The handwheel of this valve should be screwed down to the fully-closed position. The condensate recirculating valve can now be opened, and the steam auxiliary oil pump (electrical in some plants) should automatically come into operation at the correct oil pressure as the speed of the set falls. The set auxiliaries can be shut down in the following sequence : Steam to main ejector, extraction pump, alternator fans and circulating water pump. After shutting off the steam, the vacuum should be maintained and the gland sealing steam reduced in order to dry out the turbine. The gland steam is shut off after the condenser vacuum is broken, otherwise cold air would be drawn into the turbine, causing rapid cooling of the shaft, condensation, and unequal cooling of the steam rotors. Some engineers appear to prefer keeping the air ejectors operating for some time (generally about fifteen minutes) after the set has been stopped (the period depending on the capacity of the ejectors and the volume of the turbine and condenser steam space) in order to dry out the turbine and prevent rusting. An air cock may be provided on the steam chest for admitting a current of air to pass through the turbine during the drying out process. An alternative is to open the stop and throttle valves and draw air through the turbine via the steam pipe drain. The drains on the turbine can be opened either to the condenser—usually via a flash pot—or to atmosphere. The turbine main stop valve(s) can be closed, also the bled steam inlet valves to the feed-heaters, and the condensate discharge line to the boiler feed pump suction range. When the machine has come to rest, the

rolling gear can be engaged and the flushing and jacking oil pumps started. The water inlet and outlet valves to the oil and air coolers can be closed or regulated to suit conditions obtaining. Turbines not fitted with turning gear may be run for a period with no kW. load and maximum kVA. load if conditions permit of this being done in order to cool the turbine rotors gradually and reduce the possibility of vibration.

As load is taken off the alternator, so the water to the air coolers can be reduced, and where system conditions permit the machine can be loaded with kVA. as the kW. load is reduced again with the object of maintaining a uniform temperature. If this procedure is not followed premature electrical breakdown of the rotor due to distortion of the windings or to severe vibration caused by displacement of the rotor conductors may result.

On turbo-alternators not fitted with turning gear it is important to keep the auxiliary oil pump running for several hours after shutting down in order to prevent unduly high bearing temperatures. The emergency shaft governor can be tested as operating conditions permit, but it should be tested at least once a month. This can be done after the main circuit-breaker and field-breaker are opened by speeding up the set until it overspeeds by about 10 per cent., when the emergency trip should operate and close the stop and emergency valve. Should it fail to operate, the stop and emergency valve should be tripped by the hand device. The main stop valve should be only partly opened when carrying out this test, so that it can be closed immediately in case of an emergency. In the event of any possible overspeeding, the turbine can be put to atmosphere by opening the booster ejector isolating valve. It is advisable to operate the atmospheric exhaust valve periodically, or at least ensure that it works satisfactorily. These notes concerning turbo-alternator operation are only typical, but serve as a guide to general procedure.

General Operating Conditions

Throughout the development of turbo-alternators many troubles have been experienced, and even with the most modern plant certain operating difficulties present themselves and will always remain a probability unless extreme precautions are taken to mitigate against their happening. A few of these are as follows, and should always be in the minds of operating staffs :—

Failure of Circulating Water Pump. A surge on the electrical system, or some other trouble causing the tripping of the pump-

driving motors, will result in loss of cooling water supply to the condenser. The vacuum will drop, or, in other words, the pressure in the condenser steam space side will rise. Unless the cooling water supply can be immediately restored to the condenser, the back pressure will rise and at a pressure of about 17 p.s.i. the atmospheric valve should open. The low-pressure end of the turbine, and also the condenser, will soon warm up to a dangerous condition. Care should be taken not to apply circulating water until the plant has cooled down, otherwise sudden temperature change will result in cracking of the low-pressure castings, and possibly the condenser shell. In one plant the pump failed, which resulted in rapid drop in vacuum and, unfortunately, the atmospheric valve failed to operate, and the condenser shell fractured, due to over-pressure. A steam unloading device (see Chapter X, Vol. 2) is now quite often provided and comes into operation when the condenser vacuum falls below a predetermined value.

Failure of Extraction Pump. The condensate level in the steam space side of the condenser will rise to such an extent that it may flood the air suction pipes to the air ejectors. thus causing the vacuum to fall. A warning device can be fitted on the pump discharge line, so that in the event of loss of pressure an alarm is operated. A primed standby pump is usually installed, and this should be started up at once. The time required to flood a condenser would depend on the turbine steam loading.

Failure of Main Air Ejector. This is probably one of the most reliable of power plant auxiliaries, but drop in steam pressure, choking of nozzles or strainers and a sticking non-return valve are liable to cause faulty operation. The standby ejector should be immediately brought into service.

Opening of Main Circuit-Breaker. This will throw the entire load off the machine and will result in a rapid rise in speed, and may well cause the overspeed trip to operate and shut off the steam completely. The governor is generally assumed to be capable of holding the speed within 4 per cent. of the steady speed when throwing on or off the maximum continuous load, and to within $2\frac{1}{2}$ per cent. in the case of economical load. The field suppression-breaker will also open if the main breaker has opened, due to protective relay operation. There is little that can be done under these conditions, except to see that the set does not overspeed to a dangerous limit should the governor not hold it under emergency tripping speed.

Failure of Steam Supply. If the set is tripped on the steam

side, then the machine will continue to run as a synchronous motor. Should there be a possibility of restoration of steam supply immediately and gradually, the set can usually be brought back into commission without undue disturbance. Whenever a set is brought to rest it is necessary to ensure that the oil supply to the bearings is satisfactory. Reference should be made to Chapter XVIII, Vol. 2, for further information concerning protective equipment.

Plant Overhaul. Opinions appear to vary as to the frequency of overhaul of a sound-running unit, but from 12,000 to 15,000 running hours has been adopted in some power stations. Efficient cylinder drainage has an important bearing upon the life of blading. Some 80,000 tons of steam will condense into water inside the low-pressure cylinder of a 30 MW machine in 12,000 hours. Such a quantity of water, together with blade-tip speeds of 1,000 ft. per second may well result in severe blade erosion if inter-stage drainage is not efficient. How efficient it can be will be appreciated from the fact that it now requires a careful comparison of plaster casts of the blading to detect the effects of erosion after two-year periods of service and that final-stage blading is still fit for service after some 93,000 running hours.